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VOL. XXXIII MAY 1950 FASC. 5

# PERCUTANEOUS ANGIOGRAPHY OF THE VERTEBRAL ARTERY[1]

by

*E. Lindgren*

In his monography »Die cerebrale Arteriographie und Phlebographie» published in 1940, MONIZ makes the statement that in 1933, when going through a material comprising 600 carotid-angiographies, he observed that »auf fünf Aufnahmen der Truncus basilaris, die A. cerebri posterior und in einigen Fällen Kleinhirnarterien zu sehen waren». MONIZ continues: »Das Sichtbarwerden der Arterien der hinteren Schädelgrube ist offenbar dem Herabsinken der eingeführten Kontrastflüssigkeit bei einem der Fälle in die Carotis int., bei den anderen in die Carotis comm. zuzuschreiben.» I cannot find this explanation correct, however, and it is therefore surprising that as late as 1940 MONIZ did not revise his opinion from 1933. It is easy to provide evidence in this respect by making the attempt to inject the contrast into the carotid artery in the reverse direction of the blood current and observe how far the contrast reaches. In the accompanying pictures, no contrast medium can as a matter of fact be seen in the vertebral artery, though filling of the internal carotid artery and its branches as well as of the basilar artery is obtained. Actually, everyone working with cerebral angiographies will have observed that in certain cases not only the posterior cerebral artery, which frequently takes off from the carotid siphon, but also the basilar artery and its branches are filled by injection into the internal carotid artery. This is most commonly due to a wide posterior communicating artery, which provides an easy passage for the contrast. (Fig. 1.) Another vascular anomaly is less common, *i. e.* when the vertebral artery emerges from the internal carotid artery or from the common carotid artery, and passes either through a few of the transverse foramina or directly through the

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The paper was read at the Symposium Neuroradiologicum, Rotterdam, September 1949; submitted for publication, dec. 31, 1949.

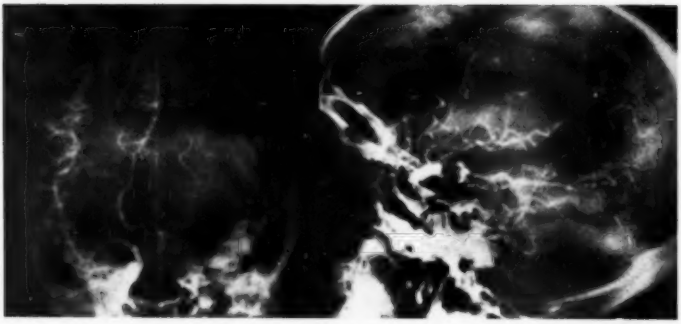

Fig. 1 a. Fig. 1 b.

Fig. 1. Filling of the upper part of the basilar artery and its branches through a thick communicating artery on the right side.

foramen magnum. Such anomalies in the course of the vertebral artery, which are known to and have been described by the anatomists are, however, according to our experience rare. Out of a series of 1,526 angiographies, we have only in 4 cases observed the vertebral artery to take off from the carotid artery and pass directly through the foramen magnum (Fig. 2). Finally it may be observed, in exceptional cases, that the vascular system has an appearance entirely deviating from the normal one, which can be seen in Fig. 3, where the posterior cerebral artery constitutes the main branch of the internal carotid artery but no cerebellar vessels are filled.

The observation made by MONIZ in 1933 was, however, of benefit in other respects, since it clarified that the patients were not injured when the contrast passed through the region of the basilar artery and that consequently it was possible to make an arteriography of this artery. MONIZ and his co-workers subsequently developed a special technique for angiography of the posterior fossa with surgical exposure of the subclavian artery and retrograde injection of the contrast after compression of the vessel.

Since then, several operative techniques based on exposure of the vertebral artery and direct injection into this vessel have been developed (OLIVECRONA, SJÖQVIST). A method suggested by BERCZELLER and KUGLER has probably not been applied to living objects, but a similar technique of percutaneous puncture had been used in a case demonstrated at the Meeting in Oslo 1948 of the Northern Society for Radiology. In 1942, KING believes himself to be the first to inject contrast into the vertebral artery after exposure of the vessel. As SUGAR, HOLDEN and POWELL point out, he describes a normal finding as an aneurysm. None of the operative

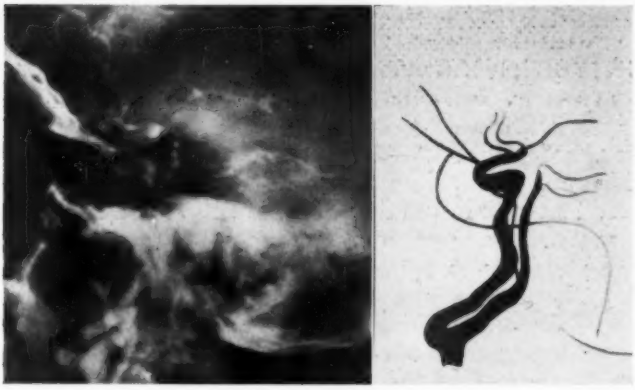

Fig. 2. The vertebral artery takes off from the carotid artery high up in the neck and passes directly through the foramen magnum.

techniques seems to have come to be more widely applied, since they all involve too many details, are time-consuming and often technically complicated and therefore give uncertain results.

Modifying MONIZ' technique, SHIMIDZU in 1937 made a percutaneous puncture of the subclavian artery, injecting the contrast after that compression of the vessel in the axilla had been carried out by an assistant.

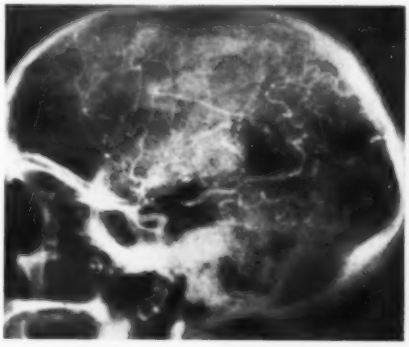

Fig. 3. The posterior cerebral artery is the main branch of the internal carotid artery.

There are some workers who regard as satisfactory the results obtained with the technique of MONIZ (*e. g.* KRAYENBUHL, LIST), while the experiences of others were not so good (SJÖQVIST). We have tried SHIMIDZU's technique in some cases but with poor results. We could follow the course of the vertebral artery in the neck in a number of cases but we could only in a few instances obtain satisfactory pictures of the intracranial vessels. This is the more to be regretted, since the percutaneous puncture of the subclavian artery is an easy procedure as a rule.

In 1940, TAKAHASHI published a new method for percutaneous angiography of the vertebral artery. His procedure was the following: a hori-

zontal line is drawn 4 cm. below the highest point of the thyroid cartilage. The line crosses the common carotid artery. From this point of intersection a line is drawn downward to a point 2 cm. lateral to the inner end of the clavicle. This line is said to correspond to the course of the vertebral artery. The needle shall be inserted on this line and the vertebral artery lies at a depth of 3.5—4.5 cm. This method does not seem to have gained wide application, since TAKAHASHI as far as I know does not seem to have any followers in the literature. We have tried this method twice without success.

Because we did not regard as successful the various methods we had tried, we began to try to puncture the vertebral artery directly from in front. In 1947, after having accomplished 24 vertebral angiographies, I was able to demonstrate our experiences before the Swedish Society for Radiology. The vessels of the posterior fossa could in 18 cases be visualized quite satisfactorily, on a. p.-views in different projections as well as on lateral views. In principle, the same technique seems to have been used of SUGAR, HOLDEN and POWELL, as it appears from a paper in the American Journal of Roentgenology 1949 without knowledge of our procedure.

Discussing LIST's: »The differential diagnosis of expanding intracranial lesions by cerebral angiography» (1946) FREEMAN, with reference to percutaneous angiography, says: »I cannot call it a refinement of the operative procedure but sometimes a picture of the posterior fossa can be obtained by injecting the vertebral artery through the same type of puncture in the neck. It is a little deeper, a little closer to the bone but one can get a picture of the posterior fossa.» It seems to me that FREEMAN here indicates a procedure that must be similar to our own and to the one employed by SUGAR, HOLDEN and POWELL. Unfortunately, FREEMAN does not seem to have further developed his method, or applied it to any great extent. LIST himself states »to be dubious about the possibility of injecting the vertebral artery through the skin, because it is a relatively small, very deeply placed vessel». He continues: »Vertebral angiography is best done by surgical exposure of the subclavian artery and retrograde injection against the current of the blood.»

The vertebral artery generally courses from the 6th cervical vertebra in the canal formed by the transverse foramina. The position of the foramen in the transverse process can be seen in Fig. 4. The ridge of bone that borders the foramen anteriorly is low and comparatively thin. Posteriorly to the foramen the transverse process is broader and higher, continuing in the superior articulate process. Regarded from the standpoint of puncture conditions, the canal that envelops the artery may be said to be closed dorsally while it is open ventrally and laterally (See Fig. 5). The artery lies ventral to the nerve bundles (Fig. 6) that emerge from

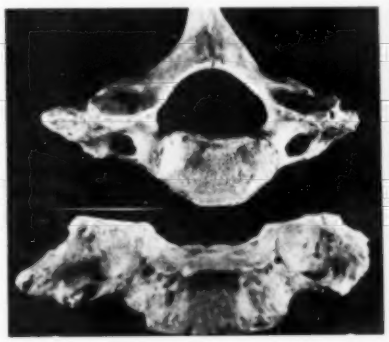

Fig. 4.

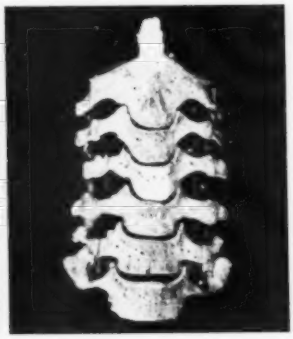

Fig. 5.

Fig. 4. A cervical vertebra. Note the position of the transverse foramen (Cf. the text).
Fig. 5. A rubber tube is inserted in the canal formed by the transverse foramina.

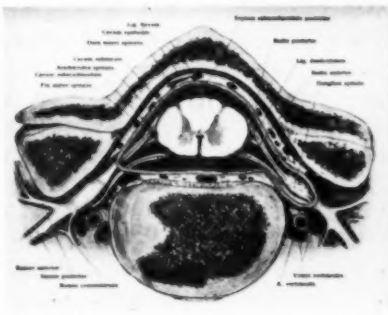

Fig. 6.

Fig. 7.

Fig. 6. A transverse section of the neck (after Corning). The vertebral artery is situated anterior to the nerv stem.
Fig. 7. An anatomical specimen showing the vertebral artery on the left side. It is clearly seen in the upper intervertebral space, but in the lower it is almost entirely covered by a disc hernia (cross).

the spinal cord and is surrounded by veins which according to anatomical descriptions mainly course ventral to the artery. If this is true, it is rather remarkable that we never happened to puncture a vein instead of the artery. However, SUGAR, HOLDEN and POWELL state that it happened to them twice. The actual position of the artery in relation to the nerve root in the same intervertebral foramen is of importance for enabling a puncture of the artery without involving the nerve.

The artery is thus under normal conditions accessible from in front, but this is not always the case in pathological states. According to our

experience, disc hernias in the cervical spinal column are not exceptional and very often they seem to be laterally situated. In such instances, the artery may be partly or completely covered from in front, as can be seen in Fig. 7. Our usual procedure is first to take plain films of the cervical spine to detect possible disc degenerations or osteophytes on the margins of the vertebrae. Where such changes occur, the anatomical conditions for disc herniation are also present and we have to consider such a possibility, even if the patient has no symptoms. In some cases, the osteophytes themselves are a hindrance for the puncture. The puncture should therefore be made at a level where no spondylous changes occur, *i. e.* fairly high up in the neck, since such changes most frequently occur in the middle or lower part of the cervical spine. The puncture is also more easily performed at a higher level, since the distance between the anterior parts of the transverse processes is often somewhat larger here than lower down.

The examination is performed either under local or under general anaesthesia. Our general procedure is the same as in percutaneous carotid angiography, the technique of which has been described in the author's article in Brit. J. of Radiology. We also use the same cassette changer as is indicated therein. It is not necessary to use the same degree of backward flexion of the head as in carotid angiography, but some degree of flexion is preferable, as in that manner the distances anteriorly between the arches are somewhat increased. Compared to the carotid artery, the vertebral artery seems to be more fixed. The proper spot of puncture is selected after studying the plain films over the cervical spine. The frontal view (a.-p. or p.-a. picture) will show the approximate position of the artery. The needle is then inserted towards the place aimed at, whereby as a rule the carotid sheath has to be drawn laterally by the left hand. The needle will thus be placed medial to the carotid artery. Because the site of the transverse process in relation to the trachea is seen on the previously taken survey-picture, we are able to determine approximately where the needle has to be pushed down. If the needle comes down directly between the transverse processes, blood is generally obtained immediately and will show up in the glass tube inserted in the rubber tube system. It often happens, however, that the needle when inserted and before any blood is obtained has struck against bone. The point of the needle is then probably resting against the anterior edge of the transverse process and has to be slowly moved in cranial direction. It then suddenly slides over the antero-superior margin of the transverse process on to the depth where as a rule it will encounter the vertebral artery. Has the puncture taken place in the manner now described, the patient will not have felt any discomfort. If the point of the needle has been inserted too far medially it will not come down between the transverse processes but

hit against the body of the vertebra. If it is inserted too far in lateral direction it will encounter nerve bundles and the patient will feel pains, either in the shoulder or radiating down the arm, depending on the level of the puncture. Then, the point of the needle has to be shifted more medially. When the examination is performed under general anaesthesia, the investigator has no possibility of guidance by the patient's sensations of pain and must therefore exercise particular care in palpating with the needle the transverse process. It is possible, in such a case, that an unrestricted searching with the needle causes puncture injuries to the nerves. This is avoided if the investigation is performed under local anaestesia in superficial tissues. When pains are inflicted upon the patient, it is possible, on the other hand, that these lead to a contraction of the vessel and that the puncture of the vessel thereby may be rendered more difficult.

When the needle has hit upon the vertebral artery and the eye of the needle lies in the vessel, the blood rises without difficulty into the tube system, thereby starting the evacuation of the saline or citrate solution that it contains. It is, however, not sufficient to notice this fact, since one has to wait for the blood actually to appear in the glass tube. There is a possibility, if the needle has been inserted far laterally and the needle consequently is directed fairly strongly medially, that the vertebral artery has escaped the needle and that the subarachnoid space is instead punctured. In that case the solution in the tube system will also be forced to drip out. This has happened to us twice. Great risks are involved, if a contrast medium of the perabrodil type is injected at this high level into the subarachnoid space and it is therefore important cautiously to control what is being punctured.

If no blood is obtained when the needle has been inserted between a pair of transverse processes, this may be due to several causes. Disregarding the possibility of coagulation in the point of the needle or absorption of some particle of tissue in the eye of the needle, the most common cause seems to be that the needle has passed through the vessel. In the puncture process, the needle may have compressed the walls of the vessel and passed out on the opposite side without causing blood to appear in the tube system. In that case, the point of the needle shall be slowly withdrawn, while lifting the point a little. It then can be felt clearly, how the rear wall of the vessel glides over the point of the needle and, after waiting a moment, blood will rise in the system. We have found that the vertebral artery varies greatly in width. Quite often, the vessel is wide and of about the same size as the internal carotid, while sometimes it is narrow to an extent which makes a satisfactory puncture impossible. Occasionally, it may thus be impossible to introduce any contrast, even if blood has been obtained. It may happen

that only part of the eye of the needle is placed in the vessel, while the other part may lie in the wall or, perhaps, outside of it. Evidence of this will appear if the patient feels pain down the arm, which is absent when all the contrast falls within the vessel. In view hereof it would be preferable to use short-bevelled needles, but since necessarily such needles are also more blunt, they are considerably more difficult to use for the puncture. The ideal needle is a sharp one that cuts the tissue without displacing it.

It seems too early as yet to estimate how often the percutaneous puncture of the vertebral artery succeeds. SUGAR, HOLDEN and POWELL except in 2 cases obtained useful pictures on 20 patients. We have found the results to depend very much on the skill and experience of the operator but also to a large extent on other factors such as the width of the vessel and on eventual anomalies or changes in the spinal column. Appreciating the rate of successful punctures with our present experience and counting with the ordinary hospital clientele, *i. e.* with patients in their middle age or above, we should estimate that in about two thirds of the cases the percutaneous puncture is possible. About the same advantages and disadvantages are present as with other percutaneous angiographic methods. Possibly, the advantages predominate, since compared to the carotid artery a surgical exposure of the vertebral artery is a considerably more difficult procedure, and, further, since the adoption of MONIZ' technique with retrograde injection into the subclavian artery at least in our experience has not given satisfactory results. We therefore recommend that first an attempt at percutaneous puncture should be made. If this is not successful, we consider RADNER's technique of setting up a catheter through the radial artery to the vertebral artery to be the best method. It is, however, considerably more complicated than the percutaneous method and not infallible either as we have found.

Up to the present, we have carried out 60 percutaneous vertebral angiographies. That this is all may perhaps seem peculiar, as we have used the technique since 1947, but we have as a matter of fact been somewhat moderate as regards the choice of indicating conditions. It is true that the examination generally proceeds without discomfort to the patient. When a water soluble contrast medium is injected into the internal carotid artery, the patient feels heat, or other similar sensations, when the contrast passes through the intracranial branches. When the contrast passes through the vertebral artery and its branches, on the contrary, the majority of patients seem to be much less affected. Yet, we have had two serious complications and this is the reason for our moderation. One was a case where the patient after the examination became blind for 3 days which was followed by optic aphasia during 7 days. Thereafter, the symptoms diminished and finally disappeared

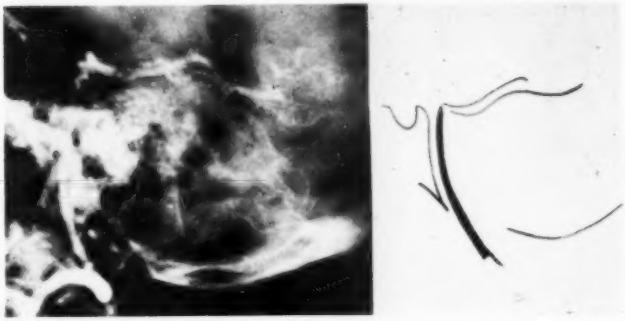

Fig. 8. Normal position of the basilar artery, following clivus.

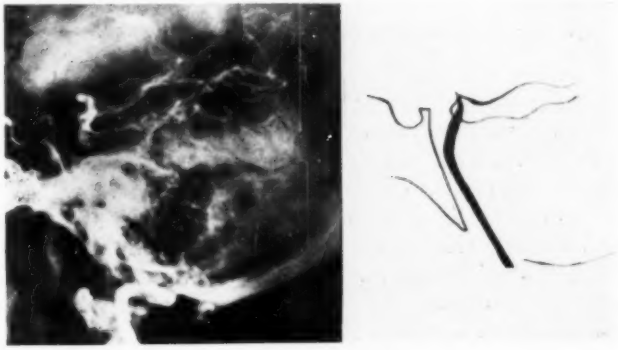

Fig. 9. Normal position of the basilar artery. The upper part is bent backwards.

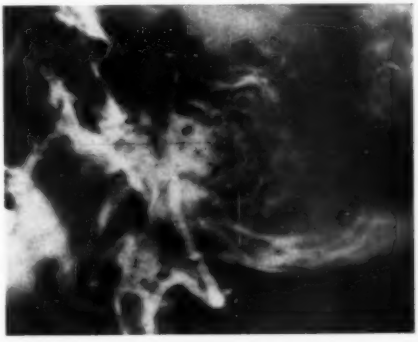

Fig. 10. The course of the basilar artery in a case of acoustic tumour.

Fig. 11 a. Fig. 11 b.

Fig. 11. Normal case. a) Just above the foramen magnum the basilar artery makes a slight curve (arrow). b) Venous phase.

completely without leaving any after effects. In the second case, the patient became dazed: he was unaware of where he was and of what had been done to him. That condition lasted about 24 hours when it ceased without leaving subjective or objective after effects. I should point out that we have always employed 35 % umbradil, because in our experience with carotid angiographies this contrast medium has been found to leave the patients less affected. This has later been corroborated by T. Broman and Olle Olsson in their experimental investigations.

Detailed information about the course of the basilar artery is rarely found in the literature. Descriptions offered in current anatomical textbooks are of moderate value, because they are not based upon conditions in life. The few arteriographic statements in the literature are not very useful either. Moniz states: »So oft es uns gelang die A. basilaris am Lebenden sichtbar zu machen war die Lage stets dieselbe.» The conclusion might be drawn that variations in position do not occur but this is quite contrary to our experience. Moniz describes the position of the basilar artery as being »senkrecht zur Schädelbasis», which does not seem correct if I rightly understand its meaning. In another paragraph he says: »Zuweilen erscheint auf Arteriogrammen der hinteren Schädelgrube die A. basilaris sogar leicht nach hinten geneigt.»

In the sagittal plane, *i. e.* on lateral view, we have observed two alternatives in the position of the basilar artery. The one is that the artery courses parallel to the clivus, the degree of its curvature then being dependent on how the clivus bends (Fig. 8). It continues upwards and as a rule divides at the level of or just above the posterior clinoid process. The artery may course close to the clivus or at a distance of about $^1/_2$ cm.

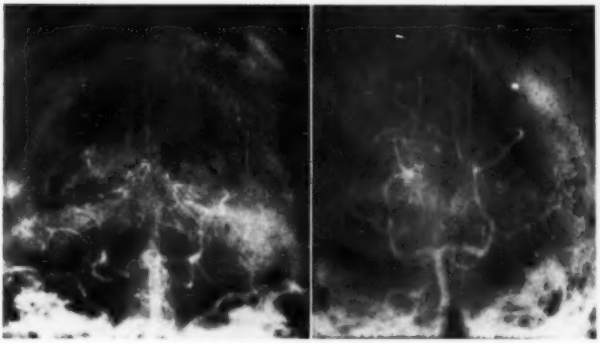

Fig. 12. Normal a. p.-pictures.

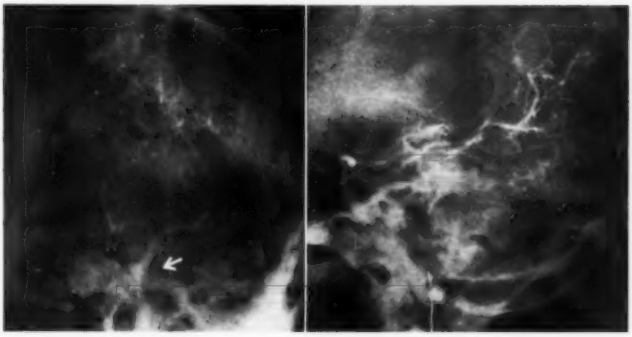

Fig. 13 a. Fig. 13 b.

Fig. 13. Normal case. a) A. p.-picture. The basilar artery makes a sharp bend to the right (arrow). b) Same case. Lateral picture.

The other alternative in the course of the vessel is that the inferior portion lies against the clivus while its superior portion bends backwards (Fig. 9), the backward bend sometimes being gradual but in many cases fairly sharp. In the latter case it can easily be misinterpreted as depending on a dislocation. Yet, we have not observed the artery in normal cases to intersect the curvature described by clivus. In some cases of acoustic tumours we have, however, observed the basilar artery to have such a position (See Fig. 10). Sometimes, the artery makes a bend backwards just above the foramen magnum (See Fig. 11). Also on a. p. views, *i. e.* the position in the frontal plane, may variations in the course of the artery occur. Though ordinarily the vessel runs on the medial line (Fig. 12), comparatively large bends to both sides can be present without

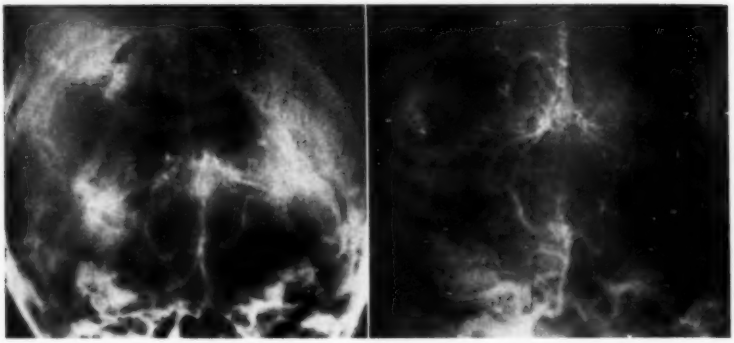

Fig. 14 a. Fig. 14 b.

Fig. 14. Anomalies in the course of the branches of the basilar artery.

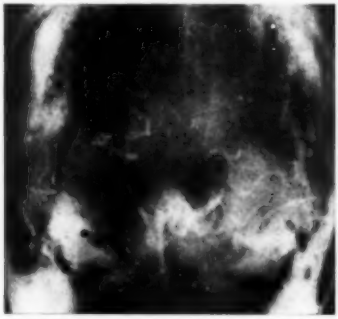

Fig. 15. Acoustic tumour. Dislocation and straightening of the branches on the right side.

being caused by tumour (Fig. 13). These facts are very important to know so that conclusions as to the presence of tumour are not based on the sole evidence of such variations in the position of the artery.

The division of the basilar artery into the posterior cerebral and the superior cerebellar arteries may be symmetrical, but not infrequently small asymmetries occur. The pictures shown in Fig. 14 in all probability represent anomalies. Anyway, there are no clinical evidences of tumour in the posterior fossa and the pneumographic examination of the posterior fossa with the author's technique, showed normal appearance. There is in principle no great difference to be seen in the course of the vessels if one compares these cases (especially the case in fig. 14 b) with the one illustrated in Fig. 15, which represents the conditions in

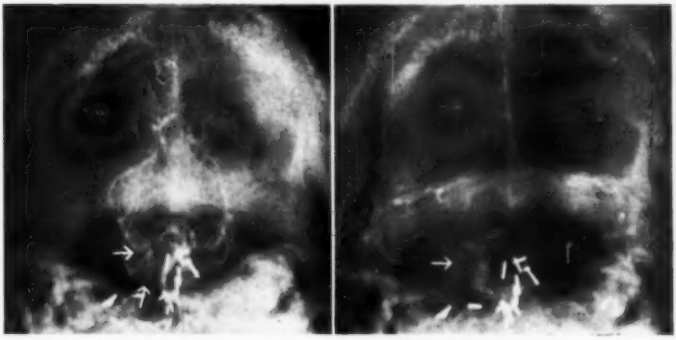

Fig. 16 a. Fig. 16 b.

Fig. 16. A. p.-picture of a cerebellar angioma: a) arterial phase; b) venous phase. The hypervascularized area (arrow) is more distinct in the latter picture.

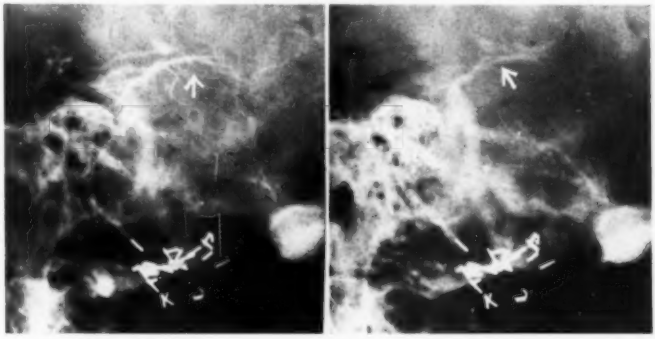

Fig. 17 a. Fig. 17 b.

Fig. 17. Same case, lateral views (dislocated vessels [arrow] cf the text): a) arterial phase; b) venous phase.

the presence of an acoustic tumour on the right side. In the tumour case, the branches that take off from the posterior cerebral and the superior cerebellar arteries are, however, straightened.

In consideration of the variational conditions now exposed it seems necessary with our present experience to judge with caution the presence and localization of an expanding lesion, when this is done exclusively on the evidence of dislocated vessels. In our opinion the localization of the tumour is more definite with the aid of pneumography and the size of the lesion is also more accurately determined.

However, when recurrence of tumour is suspected, the angiographic method may prove valuable, since the pneumographic changes may be

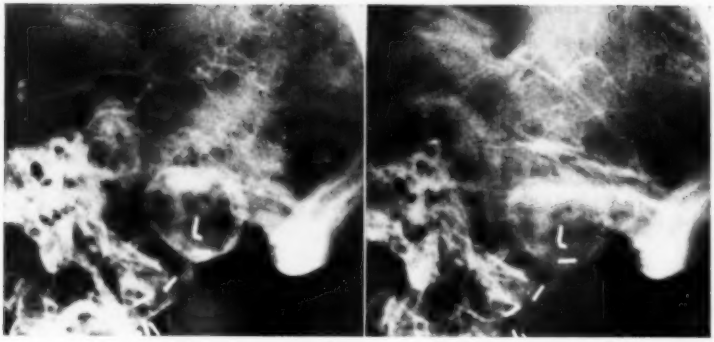

Fig. 18 a. Fig. 18 b.

**Fig. 18.** Lateral picture of a cerebellar angioma. a) arterial phase; b) venous phase.

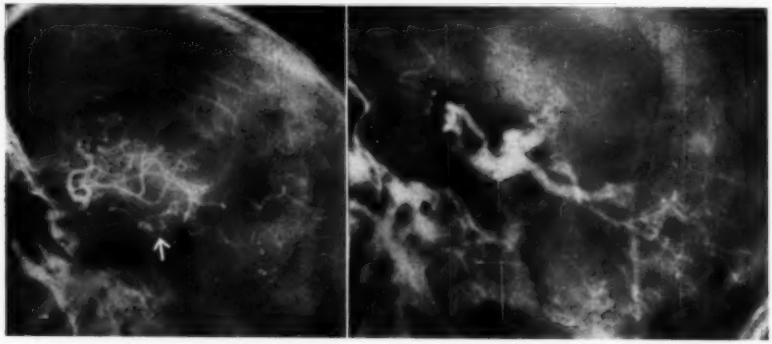

Fig. 19 a. Fig. 19 b.

**Fig. 19.** a) Arterio-venous aneurysm (Cf. the text). Injection into the internal carotid artery. b) Injection into the vertebral artery.

difficult correctly to interpret, if the patient has been operated upon before. Then angiography can be of great value, especially if the process is vascular.

H. M. ♂ born 1906. In August 1946: nausea, vomiting, balance disturbance, vertigo, headache in the back of the head, gradually diminishing vision. On the 4th of November, after ventriculography which disclosed a tumour to the right of the midline in the posterior fossa, the patient was operated upon: Removal of a vascular tumour, the size of a walnut, and of a cyst situated in the medial part of the right cerebellar hemisphere (LEKSELL). *Pad:* Cerebellar angioma.

Since then free of symptoms till the middle of September 1948, when trouble reappeared in the form of increasing headaches, nausea, vertigo, vomiting, gustatory hallucinations and speach difficulties. Angiography disclosed a small region with pathological

vessels, most clearly visualized on a. p. picture in the venous phase (Fig. 16). The pathological vessels were less distinct on the lateral view (Fig. 17), but this view as compared to the frontal view brought forward more clearly the dislocation of the vessels, especially of the superior cerebellar artery. In general, it seems easier accurately to estimate the size of an expanding process with the aid of the pneumographic picture. Only some part of the process may be hypervascularized. In this case, the vascularized region is small but the vascular dislocations indicate that the process must be larger. It is, however, hardly possible to suspect that it could be as great as it actually was. Operation on the 18th of November (LEKSELL): In vermis and the right cerebellar hemisphere, extirpation of an angioma, the size of a walnut, surrounded by a cyst greater than a walnut.

Another case is illustrated by the pictures shown in Fig. 18 where the tumour is easily localized on account of the encircling vessels.

The principal indications for angiography of the vertebral artery are in our opinion clinical suspicions of vascular changes, such as aneurysms and arteriovenous aneurysms. The conditions in the presence of an arteriovenous aneurysm are illustrated by the following case.

L. E. Ö. ♀ 35 years. For 5—7 years headache with no distinct localization. In the evening on the 8th of January 1949, acute headache and half an hour later unconsciousness during 24 hours with paralysis of the right side of some hours' duration. Admitted to hospital where defect in the right visual field was detected. Bloody fluid was obtained by lumbar puncture. Status in August: Homonymous hemianopsia of the right side. Otherwise no neurological signs. Angiography in the internal carotid showed the choroid artery to be wider than usual, some small and irregular pathological vessels being filled from this artery (Fig. 19 a). Angiography into the vertebral artery: Arteriovenous aneurysm, the afferent vessels coming chiefly from the posterior cerebral artery (Fig. 19 b). The small vessels which are filled from the choroid artery correspond to the upper portion of the aneurysm.

## SUMMARY

A short description is given of the technique developed at the Roentgen Department of the Seraphimerlasarettet, Stockholm, for percutaneous angiography of the vertebral artery. In connection herewith normal variations occurring with some vessels of the posterior fossa are described. Examples are given to demonstrate the range of applicability of the method of vertebral angiography.

## ZUSAMMENFASSUNG

Eine kurze Beschreibung der in der Röntgenklinik des Serafimerlasarettes krankenhauses zu Stockholm entwickelten Technik zur perkutanen Angiographie der Art. vertebralis. Bei dieser Gelegenheit werden auch die vorkommenden normalen Variationen gewisser Gefässe der hinteren Schädelgrube beschrieben. Es werden Beispiele gegeben, die die Ausdehnung des Verwendungsgebietes der Methode der vertebralen Angiographie veranschaulichen.

## RÉSUMÉ

L'auteur expose brièvement la technique d'angiographie transcutanée de l'artère vertébrale, telle qu'elle a été mise au point dans le service Radiologique de Serafimerlasarettet à Stockholm. A ce propos il décrit les variations que certains vaisseaux de la fosse postérieure peuvent normalement présenter. Il apporte des exemples cliniques pour montrer l'étendue du champ d'application de cette méthode d'angiographie vertébrale.

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FROM THE I. ROENTGENDIAGNOSTIC DEPARTMENT OF SÖDERSJUKHUSET, STOCKHOLM, SWEDEN (CHIEF: DOCENT G. JÖNSSON) IN COOPERATION WITH THE II. MEDICAL CLINIC OF SÖDERSJUKHUSET, STOCKHOLM (CHIEF: PROF. G. NYLIN).

# PATENT DUCTUS ARTERIOUS[1]

## Diagnosis by Introduction of Catheter through Ductus from Pulmonary Artery into Aorta

by

*Johan Karnell, Gunnar Jönsson* and *Bror Brodén*

In 1948 we discussed the possibilities of diagnosing a patent ductus roentgenologically. The angiocardiographic method had then been in use for about ten years but no one had succeeded in visualizing the ductus directly and the indirect signs observed had proved to be more or less unreliable. Castellanos' method using counter-current injection of opaque substance into the brachial artery was not suitable for routine purposes, in our opinion, at any rate not for adults and older children. We described two cases in which we had diagnosed a patent ductus by thoracic aortography. In both instances the opaque substance passed over from the aorta to the pulmonary artery and the patent ductus was opacified. Since publishing this paper, we have made the same observations in sixteen more cases examined with thoracic aortography. Aortography is the only satisfactory roentgenologic method for the examination of patent ductus which can be used routinely for adults. In children, it is hard to get a technically successful aortogram and it is quite impossible in infants because their arteries are not wide enough to allow the insertion of a catheter into the aorta.

However, there is another way of visualizing a patent ductus directly. If a wide ductus is present, it is often easy to manoeuvre a catheter inserted in the pulmonary artery through the ductus into the aorta. This is the most direct and undisputable way there is of establishing the presence of a patent ductus. It does not involve any new and troublesome manipulation for the patient. The heart must be catheterized anyway

[1] Submitted for publication Febr. 6, 1950.

and when the catheter is in the pulmonary artery it can be seen whether it can be pushed farther through a patent ductus. If no success is achieved after a few minutes, the attempt should be given up. Our experience, admittedly limited, is that there is no point trying much longer. Unless a ductus is found almost at once, the chances are that none is present or that it is not so wide that catheterization is possible in the amount of time at disposal.

During the past year we have catheterized 10 cases of patent ductus and we were able to push the catheter through the ductus in not less than 4 of these cases. Patent ductus is not a rare abnormality and countless catheterizations have been and are being done all over the world to establish its presence. It can be taken for granted, therefore, that we are not the first to insert the catheter through the ductus. It is surprising, however, that no one has called attention to the diagnostic value of this procedure.

## Case Reports

*Case 1.* A. S. W., female, aged 21. The patient had a rumbling, continuous murmur.

On *cardiac catheterization* the catheter (no. 9F) suddenly passed from the pulmonary artery into the aorta and up toward the left carotid artery. The pressure was high, at least 150 cm. of water. Roentgen pictures were taken with the catheter in this position (fig. 1). It did not stay there long enough, however, to allow injection of opaque substance into the aorta. Blood gas analysis showed 12.1 volumes per cent in the right ventricle and 15.1 volumes per cent in the pulmonary artery. The pressure measured 25 cm. of fluid in the right ventricle and 35 cm. in the pulmonary artery.

*Operation* (CRAFOORD) revealed a 3 mm. long patent ductus with an outer diameter of 12 mm. and an extremely thin wall. The ductus was ligated and a 60 per cent solution of glucose was injected between the ligatures.

*Case 2.* K. A., female, aged 10. The patient had a rumbling continuous murmur.

*Cardiac catheterization and angiocardiography* were performed. A catheter (no. 8F) was inserted via a left cubital vein into the pulmonary artery and from there directly and easily through a patent ductus into the aorta. With the tip of the catheter lying in the aorta beside the ductus, 35 cc. of a 70 per cent umbradil solution were injected in the space of three seconds (fig. 2).

*Operation* revealed a patent ductus about 5 mm. long with an outer diameter of 12 mm. It was ligated and a 60 per cent solution of glucose injected between the ligatures.

*Case 3.* B. B., male, aged 13. Signs of coarctation of the aorta were present. In addition, a typical continuous murmur was heard over the pulmonary artery. The pulmonary second sound was accentuated.

As the patient appeared to be suffering from a patent ductus in addition to coarctation of the aorta, *cardiac catheterization* was performed. It proved easy to insert the catheter through a patent ductus into the aorta. There the tip turned upward making it pos-

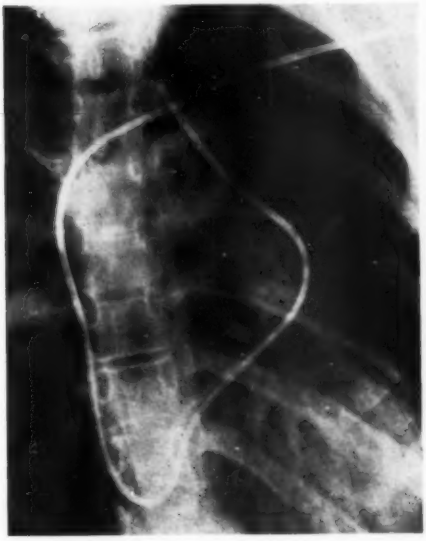

Fig. 1. The catheter passed from the pulmonary artery into the aorta.

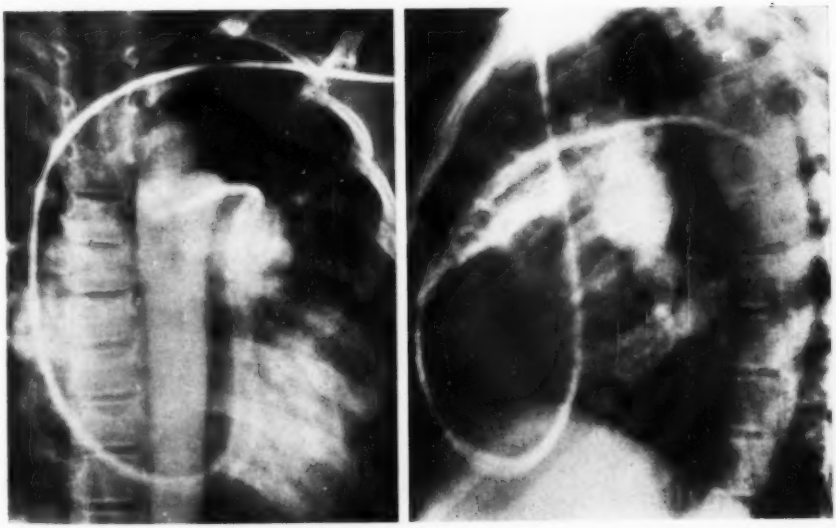

Fig. 2. The catheter was introduced through a patent ductus into the aorta. 35 cc. of a 70 per cent umbradil solution were injected.

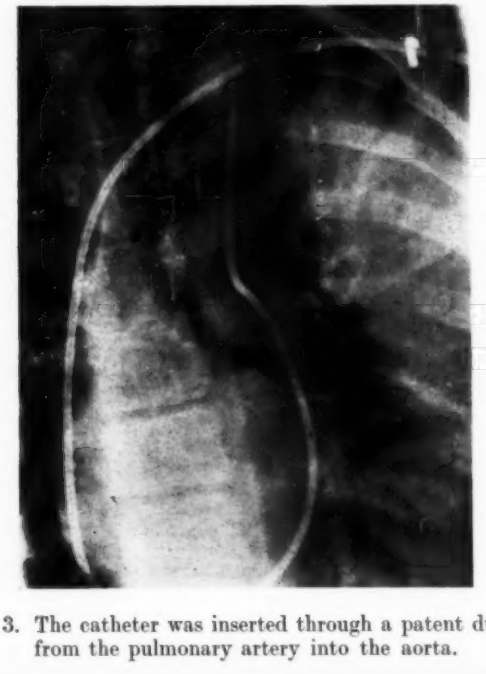

Fig. 3. The catheter was inserted through a patent ductus from the pulmonary artery into the aorta.

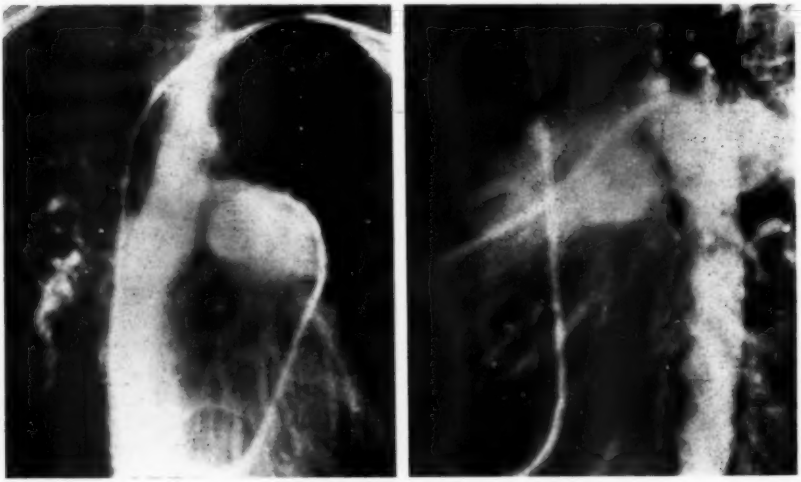

Fig. 4. The catheter passed through a patent ductus from the pulmonary artery into the aorta. 80 cc. of a 50 per cent solution were injected.

sible to insert the catheter up into the subclavian or carotid artery. However, it could not be made to remain in the aorta steadily enough to allow injection of contrast medium. (Fig. 3.) Blood gas analysis showed 10.3 volumes per cent of oxygen in the right ventricle and 12.1 volumes per cent in the pulmonary artery. The pressure in the pulmonary artery measured 80 cm. of water.

*Operation* (CRAFOORD) revealed typical coarctation of the aorta and a patent ductus about 10 mm. both in length and outer diameter. The duct was divided and the pulmonary artery sutured. The aorta was resected according to the CRAFOORD method.

*Case 4.* L. O., female, aged 17. There was a rumbling murmur extending from systole over into diastole. It was not continuous.

*Cardiac catheterization and angiocardiography* were performed. A catheter (no. 9F) was inserted through a left cubital vein to the pulmonary artery. From there it passed directly without any particular manipulation through a patent ductus into the aorta. It was possible to carry the catheter up into the aortic arch, but from there it kept slipping up into the left common carotid artery. Because of this we were afraid that we might cause cerebral complications if we injected the dye into the arch. We drew back the catheter, therefore, to bring its tip into the aorta beside the patent ductus, and injected 80 cc. of a 50 per cent solution of umbradil in the space of three seconds (fig. 4). Blood gas analysis revealed 12.2 volumes per cent in the right ventricle and 13.3 volumes in the pulmonary artery. The pressure measured 22 cm. of fluid in the right ventricle and 85 cm. in the pulmonary artery.

*Operation* (CRAFOORD) revealed a patent ductus about 5 mm. long and about 2 cm. in outer diameter. The duct was divided and the pulmonary artery and aorta sutured.

## Discussion

It seems as though a widely patent ductus is not seldom accompanied by atypical clinical signs. LEVINE described a case in which only a slight pulmonary systolic murmur was heard on auscultation. Speaking of the murmur accompanying a patent ductus, he said:

> The term »machinery murmur» is often used to describe the character of the murmur of patent ductus. It is true that in many instances there seems to be a continuous noise with variations in intensity. However, it often fails to show any grating quality. It may be blowing and what is more important it may have two distinct components, systolic and diastolic, just as is heard in cases of aortic stenosis and insufficiency and then be designated a »to and fro» murmur.

LEVINE also pointed out that the pressure in the pulmonary artery may gradually grow so great that it approaches that in the aorta resulting in little left to right shunt.

Our entire series of 22 cases of patent ductus contain 5 with an atypical murmur. One of them was the case 4 just described. In the other four cases no attempt was made to insert the catheter into the ductus.

The clinical observations alone in these cases were not enough for the diagnosis. Even if the oxygen content is so much higher in the pulmonary artery than in the right ventricle that there must be an interarterial shunt, it does not prove that a patent ductus is present. Espe-

cially if the murmur is not continuous but has distinct systolic and diastolic components, the possibility of communication between one of the aortic sinuses of Valsalva and the pulmonary conus or artery must be taken into consideration. It is nearly always possible to see whether a patent ductus is present by using thoracic aortography. First, however, one should always try to perform a direct catheterization of the ductus itself.

Every time the catheterization was successful there was wide communication between the aorta and pulmonary artery. In case 4 the auscultatory observations were quite atypical, in the other cases a continuous murmur was heard. In no case was it possible to visualize the ductus completely and in detail with the opaque substance. In two cases the catheter did not stay long enough in the aorta to permit an injection but was pushed back by the blood stream into the pulmonary artery. In a third case the tip of the catheter went down into the descendent aorta. It was placed in the aorta immediately beside the origin of the ductus when the injection was made, but because of the blood stream most of the medium finished up below the ductus. Only a small amount passed over to the pulmonary artery. In the fourth case we were able to get the catheter up to the aortic arch but the slightest movement caused it to slide up into one of the carotid arteries. To inject opaque substance under such conditions would have endangered the life of the patient. For this reason, we had to draw back the catheter to the origin of the ductus and the pictures we obtained resembled those in case 3. No details regarding the length and breadth of the ductus could be learned from the pictures.

It may be that the technique of catheterization and injection can be improved so as to enable distinct visualization of the ductus. Even now, however, the method is a valuable one. If it is possible to insert a catheter from the pulmonary artery directly into the aorta, what more proof can one ask of the presence of a patent ductus?

## SUMMARY

When a patent ductus is very wide, it is often easy to insert a catheter through it from the pulmonary artery into the aorta and in this way establish the diagnosis roentgenologically. Attempts can be made to do so when the heart is catheterized for measurement of the blood gases and pressure. The latter operation has to be done anyway and so the manoeuvre does not involve any extra interference or additional strain on the patient.

## ZUSAMMENFASSUNG

Wenn ein Ductus Botalli sehr weit ist, so ist es oft leicht, einen Katheter von der Pulmonalarterie aus durch denselben in die Aorta einzuführen. Man soll versuchen, dies zu tun, wenn das Herz zwecks Messung der Blutgase und des Druckes katheteri-

siert wird. Dieses Verfahren bedeutet dann keinen extra Eingriff und keine zusätzliche Belastung des Patienten.

## RÉSUMÉ

Quand le canal astériel de Botal est très large il est souvent facile d'introduire par lui une sonde de l'artère pulmonaire jusque dans l'aorte. On peut essayer de procéder de cette façon lorsqu'on cathétérise le cœur pour mesurer les gaz du sang et sa pression. Comme cette opération doit être pratiquée en tout état de cause, la manœuvre n'implique aucune intervention supplémentaire ni aucune fatigue surajoutée pour le malade.

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AUS DER GYNÄKOLOGISCHEN ABTEILUNG DES ZENTRALINSTITUTS FÜR STRAHLENTERAPIE ZU HELSINKI, FINNLAND (DOZ. DR. V. KAHANPÄÄ)

# ÜBER DAS FIEBER IM ZUSAMMENHANG MIT BRACHYRADIUMBEHANDLUNG BEI SONST UNKOMPLIZIERTEN KOLLUMKARZINOMFÄLLEN[1]

von

*V. Kahanpää*

Das Kollumkarzinom ist sofort nach dem Auftreten der klinischen Symptome besonders empfänglich für lokale Infektionen. Die lockere Tumorfläche zerreisst leicht, und die vaginalen Bakterien dringen in das blutimbibierte Tumorgewebe ein, worin Nekrosen und Ulzerationen entstehen. Ein Zeichen für die fortwährende Infektion ist der zwischen den Blutungen auftretende schmutzigeitrige und bald übelriechende Fluor. Im späteren Stadium, wenn das Neoplasma grösseren Umfang erreicht hat, und die Infektion tiefer hineingedrungen ist, stellt sich regelmässig auch Fieber ein — auch dann, wenn sich als Ursache dafür keine Ausbreitung der Infektion in die Umgebung des Tumorgewebes (Salpingitis, Pelveoperitonitis, Abscessus pelvis, Parametritis, Phlebitis), in die Harnwege oder selten zu Allgemeininfektion feststellen lässt, ganz abgesehen von völlig andersartigen fiebererregenden Komplikationen.

Über die frühzeitige Infektion des Kollumkarzinoms sprechen auch die Operationserfahrungen ihre eigene Sprache. In den verschiedenen Statistiken bilden ja die an Peritonitis und anderen infektiösen Komplikationen Gestorbenen die Mehrheit in der postoperativen Mortalität, welche letztere sehr hoch gewesen ist, besonders ehe der Bakterienflora der Vagina die nötige Aufmerksamkeit vor der Operation zugewandt wurde. So stellte z. B. Dehler im Jahre 1928 bei 2/3 der Kollumkarzinomfälle Streptokokken fest, von welchen die meisten Stämme sehr pathogen waren.

Auch bei der Brachyradiumbehandlung bildet die Infektion des Tumors eine mit Recht gefürchtete Gefahr. Diese Gefahr ist umso drohender, je weiter das Karzinom an sich und dessen Infektion vor Beginn

[1] Bei der Red. am 14. II. 1950 eingegangen.

der Behandlung sich ausgebreitet haben — von Infektion der Umgebung ganz zu schweigen. Das Operieren in dem entzündeten und lockeren Karzinomgewebe, durch welches man dilatierend den Weg für die intrauterine Radiumapplikation bahnen muss, vermehrt die Ausbreitungsmöglichkeiten der Infektion entweder durch die Uterushöhle hinauf in die Tuben und weiter vielleicht in die Peritonealhöhle oder seitwärts vom Tumor in die Parametrien. Auch die Radiumapplikation selbst und die damit verbundene dichte Tamponierung der Vagina sollen die genannten Infektionsgefahren der Umgebung vermehren, weil die unteren Partien des Genitalkanals auf diese Weise für längere Zeit verschlossen werden, was möglich *Retention des Exsudates* und Ausbreitung desselben entweder aufwärts weiter in den Genitalkanal oder durch Gewebsrisse seitwärts zur Folge hätte.

Ausser natürlich vorsichtigem Arbeiten sowohl beim Untersuchen als auch bei der Behandlung, wozu schon die Gefahr der Blutung und der Provokation von Metastasen zwingt, hat die Furcht vor der Infektion und Retention mancherorts zum Gebrauch von Hohldilatatoren (DIETEL) und zur Konstruktion von verschiedenen Kolpostaten geführt, um auf die Tamponierung verzichten zu können (GERICKE, GUILERA, DAUBRESSE-MORELLE und SCHMIT, RITALA u. a. m.). Aus den gleichen Gründen ist die Stockholmer fraktionierte Behandlungsmethode im Vergleich zu der einphasigen Behandlung als vorteilhaft bezeichnet worden (ANSELMINO und OEHLKE, DUCUING und NÈGRE, FINDLEY, HAMANN und GOEBEL, KESSLER und SCHMIDT, KIRCHOFF und DRENCKHAHN, PLATE, SCHROEDER, WIMHÖFER).

Mehr Interesse in diesem Zusammenhang bietet jedoch die in dem gleichen Sinne vorgebrachte *Forderung, bei Fiebersteigerung über eine gewisse Grenze die Gazetamponen und die Radiumpackungen zu entfernen, mit anderen Worten die Behandlung sofort zu unterbrechen.*

Dieser Gesichtspunkt dürfte ebenso alt sein wie die radiologische Behandlung der Kollumkarzinome an sich und wird immer noch allgemein anerkannt, wenn auch die Grenze des zur Unterbrechung der Behandlung »zwingenden» Fiebers in den verschiedenen Anstalten etwas variiert, meistens zwischen 38—39° C ax. (HEYMAN, DUCUING und NÈGRE, BROUHA und VAN PEE, TRUELSEN u. a. m.). Geringe Temperatursteigerung im Zusammenhang mit der lokalen Behandlung hingegen ist im allgemeinen als ungefährlich betrachtet worden, z. B. TRUELSEN (1949) schreibt hierüber: »A subfebrile reaction — unattended with other symptoms — being so common that it must be regarded a normal phenomenon with no influence on the farther course. In subfebrile cases the 2nd radiumapplication can always be made when planned, whereas it must often be postponed, if the temperature is higher.» Subfebrile Fälle waren in TRUELSENS Material (Radiumstationen i København) 41.8 % enthalten, bei uns im

Strahlenbehandlungsinstitut 45 % (KAHANPÄÄ). — Fälle, bei denen das Fieber während der Behandlung oder danach mindestens einmal über 38° C ax. stieg, kamen bei uns $16.3 \pm 2.7$ % vor, bei TRUELSEN entsprechend 23.4 %. Auch ist deutlich festgestellt worden, dass die Temperatursteigerungen umso häufiger sind, je weiter fortgeschrittene Karzinomfälle in Frage stehen.

Die erwähnte Dissertation von TRUELSEN enthält auch interessante Zahlen über den schlechten Einfluss des Fieberanstieges auf die 5-Jahresresultate. Von den Fällen mit langdauernder Temperatursteigerung war nahezu die Hälfte solche, bei denen sich als Ursache für das Fieber klinisch keine Symptome von Entzündungsprozessen im Becken ausserhalb des Tumors feststellen liessen.

Die schlechte Prognose der fiebrigen Fälle hat man damit erklären wollen, dass das Radium auf das entzündete neoplastische Gewebe nicht ebenso günstig einwirke wie auf nicht entzündetes. Auch soll bei den Fieberpatientinnen die Widerstandskraft des Organismus geschwächt sein, so dass das gesunde umgebende Gewebe nicht ebenso vorteilhaft gegen das Karzinom zu reagieren vermöchte wie in fieberfreien Fällen. TRUELSEN erwähnt noch über einen Umstand, welcher auch zweifellos hier Bedeutung hat. Wegen der Fieberperiode wird die Pause zwischen den Behandlungen zu lang, und die Therapie verliert an Wirksamkeit.

## Eigene Beobachtungen und Versuche

Als ich im Herbst 1944 meinen Dienst in der gynäkologischen Abteilung unseres Strahlenbehandlungsinstituts antrat, war es auch dort die Regel, dass bei Temperatursteigerung über 38.0° C ax. die Radiumbehandlung sofort unterbrochen wurde. Desgleichen verhielt man sich zu den schon von Anfang an fiebernden Fällen mit grösster Vorsicht. Auch subfebrile Fälle wurden in Bettruhe gehalten, und mit Hilfe von Medikation wurde versucht, den Temperaturanstieg vor Behandlungsbeginn zum Verschwinden zu bringen.

In unsere Anstalt kam damals, im Dezember 1944 ein hochfiebernder Fall von Kollumkarzinom, dessen Behandlung und günstiges Behandlungsresultat meine Auffassung über die fiebrigen aber sonst unkomplizierten Fälle beeinflusst hat, und welchen ich aus diesem Grunde hier eingehend beschreiben will.

*Nr. 2453/44.* — Eine 51 Jahre alte Bäuerin. Hereditär nichts Besonderes, und die Patientin selbst hat früher keine nennenswerten Krankheiten gehabt. Menstruation begann im Alter von 13 Jahren und war das ganze Leben hindurch regelmässig. Hat 6 spontane Entbindungen gehabt und einen fieberfreien Abort. Die Menstruation blieb aus vor einem Jahr. Hat seit 9 Monaten bräunlichen, übelriechenden Ausfluss beobachtet, welcher seit 2 Monaten ständig deutlich blutig war. Die Patientin war vor 6 Wochen

in ein anderes Krankenhaus geschickt worden, wo ein grosses Kollumkarzinom diagnostiziert wurde. *Wegen hohen Fiebers wurde die Patientin zwei Wochen lang in Bettruhe gehalten, aber man wagte nicht, mit der lokalen Radiumbehandlung des Tumors zu beginnen.* Sie wurde nach Hause geschickt mit der Aufforderung, sich nach Verschwinden des Fiebers wieder zur Behandlung einzustellen! Da das Fieber zu Hause ständig ca. 38—39° hoch blieb, wandte die Patientin sich an einen Gynäkologen, welcher sie zu palliativer Behandlung in unsere Anstalt schickte.

*Bei der Aufnahme* ins Strahlenbehandlungsinstitut war der Allgemeinzustand gut. Ernährungszustand kräftig, Hautelastizität normal. Herz und Lungen auskultatorisch und röntgenologisch ohne Befund. Sahli 65 %, L. 14,500, Blutsenkungswert 17/1 St., WaR —. *Lokalbefund:* Aus der Portio hat sich ein gänseeigrosses, am unteren Pol nekrotisches, leicht blutendes »Blumenkohlkarzinom» gebildet. Der Tumor hat rechts, hinten auch die Schleimhaut des Scheidengewölbes infiltriert, auf den anderen Seiten sind die Scheidengewölbe frei. Wegen des grossen Umfangs des Tumors lassen sich per vaginam aut per rectum die Parametrien nicht exakt palpieren, es wird aber der Eindruck gewonnen, dass die linke Seite frei ist, während wiederum im rechten Parametrium mediales Infiltrat wahrgenommen wird. Das atrophische Corpus uteri über dem Tumor ist begrenzt beweglich. In der Adnexgegend keine abnorme Resistenz oder Druckempfindlichkeit. — *Diagnose: Carcinoma colli uteri gr. II.*

*Als Ursache für das Fieber (38—39°), welches schon mindestens 6 Wochen lang gedauert hatte, war keine Ausbreitung der Infektion in die Parametrien oder in die Adnexe festzustellen. Da die Patientin über keine Störungen von seiten der anderen Organe klagte, und solche auch bei der objektiven Untersuchung nicht konstatiert werden konnten, erschien es wahrscheinlich, dass das Fieber ausschliesslich durch die Infektion des grossen exophyten Portiokarzinoms bedingt war.* Daher beschloss ich, mit der Brachyradiumbehandlung zu beginnen, da diese die einzige Möglichkeit zu bieten schien.

8. 12. 44. *Radium I.* Vorsichtshalber wurden nur zwei Radiumplatten mit 60 mgEl. Ra, und zwar rechts und links vom Tumor appliziert, während auf intrauterine Applikation verzichtet wurde. Behandlungsdauer 22 St. *Es wurde beschlossen, die Radiumplatten wegen blossen Fiebers, auch wenn es hoch sein sollte, nicht zu entfernen, sofern nicht vielleicht andere Komplikationen dazu zwängen.* Vor der Applikation war die Temperatur 38.0°, und am Schluss der Behandlung war sie ad 40.6° gestiegen, aber sonstige Komplikationen waren nicht aufgetreten.

18. 12. 44. Temperatur ständig gesunken, seit mehreren Tagen subfebril. Der Portiotumor hatte nunmehr ungefähr die Grösse eines Taubeneis. Reichlicher blutigeitriger Ausfluss.

*Radium II.* Nach leicht gelingender Dilatation wurde ein Zylinder von 60 mgEl. Ra in den Tumor geschoben, eine 40 mgEl. Platte gegen die Unterfläche des Tumors. Die weite Vagina wurde mit reichlich Gazetampon zum Schutze der Blase und des Rektums tamponiert. Behandlungsdauer 22 St. — Morgentemperatur 38.2°, danach die höchste Temperatur 37.2°.

28. 12. 44. *Radium III.* Es wurde intrauterin eine 40 mgEl. Ra-Tube sowie quer gegen die Portio und das rechte Scheidengewölbe eine 80 mgEl. Ra-Platte appliziert. Behandlungsdauer 22 St.

2. 1. 45. *Lokalbefund.* Die Portio hatte sich schon zum grössten Teil glatt zurückgebildet. Nur an ihrer rechten Seite und im rechten Scheidengewölbe ein kleiner Gewebsdefekt, welcher insgesamt eine daumennagelgrosse, ziemlich reine Ulzeration bildet. — Es wurde beschlossen, eine zeitlang abzuwarten, um eventuelle Frühreaktionen von seiten des Rektums oder der Blase feststellen zu können, ehe die Radiumbehandlung möglicherweise fortgesetzt wurde. Die Patientin bekam in dieser Zeit Röntgenbehandlung.

16. 1. 45. Allgemeinbefinden gut, fortwährend fieberfrei. Keine subjektiven Beschwerden und keine Störungen seitens der Blase oder des Rektums. Aus der Scheide nur noch geringer, schleimiger Ausfluss. — Auch die oben erwähnte Ulzeration war jetzt vollkommen epithelisiert. An dieser Stelle im Parametrium lokales Gewebsinfiltrat wie Narbengewebe auf einem ca. 2 cm langen, schmalen Bezirk, sonst überall die parametralen Gewebe dünn und nachgiebig. Uterus gut beweglich.

Obwohl also der erste Eindruck von der Behandlung ausgezeichnet war, so wurde doch beschlossen, noch eine überzählige vierte Radiumapplikation vorzunehmen, weil die bisherigen Radiumdosen im Hinblick auf das Ausmass des ursprünglichen Tumors nicht gross waren, und weil die erste Applikation sehr distal gewesen war.

17. 1. 45. *Radium IV.* Intrauterin eine 40 mgEl. Ra-Tube, und quer gegen die Portio und das rechte Scheidengewölbe eine 40 mgEl. Ra-Platte. Behandlungsdauer 20. St.

26. 1. 50. Bei den regelmässig durchgeführte *Nachuntersuchungen* teilte die Patientin mit, subjektiv vollkommen gesund gewesen zu sein. Von seiten des Rektums oder der Blase waren keine Störungen aufgetreten. Auch objektiv war kein Reizidiv festzustellen. — Die Vagina ist nunmehr ca. 4 cm vom Introitus obliteriert, die Schleimhaut überall glatt. Auch per rectum wird festgestellt, dass der Uterus die Grösse eines Daumenglieds hat und etwas dextroponiert ist. Das rechte Parametrium ist geschrumpft, aber weder hier noch anderwärts im Becken abnorme Resistenzen.

In diesem Falle handelte es sich also gewissermassen um eine Zwangslage. Die Patientin hatte ein ungewöhnlich grosses und infektiertes, exophytes Kollumkarzinom. Der Fall war inoperabel und die fortgesetzte konservative Behandlung schon erfahrungsgemäss hoffnungslos. Aus diesen Gründen bekam die Patientin vollständige Brachyradiumbehandlung, ohne dass die Pausen zwischen den einzelnen Applikationen wesentlich verlängert worden wären. Vorsichtshalber und um den infektierten Tumor zu verkleinern wurde bei der ersten Behandlung nur vaginal appliziert, und es wurde beschlossen, das Radium nicht zu entfernen, auch wenn das Fieber noch so hoch anstiege, sofern keine anderen, hierzu zwingenden Gründe von seiten des Beckens oder sonst aufträten. Die Fieberreaktion (ad 40.6°) blieb auch das einzige Symptom. Während der drei nächsten Behandlungen, bei welchen auch intrauterin appliziert wurde, stieg die Temperatur wieder von neuem an, aber jedesmal weniger, um stufenweise auf ein niedrigeres Niveau zu fallen. Vor der vierten, überzähligen Behandlung war die Patientin praktisch genommen fieberfrei. — Radiumdosierung: Uterus 3,000 und Vagina 6,080, zusammen 9,080 mgEl/St. Ausserdem lange Röntgennachbehandlung (KW 190, F. 1 mm Cu, Abs. 60 cm): In das rechte Parametrium 5,820 r (berechnete Tiefendosis).

*Da seit der Behandlung der Patientin über 5 Jahre vergangen sind, und sie klinisch gesund ist, kann sie als geheilt angesehen werden.*

Die bei der Behandlung des oben beschriebenen Falles gemachten günstigen Erfahrungen haben mich dazu ermutigt, die gleiche Richtung

bei der Behandlung der fiebernden, aber sonst unkomplizierten Kollumkarzinomfälle zu befolgen. Mit unkomplizierten Fällen sind hier solche gemeint, bei denen sich als Ursache für das Fieber nichts anderes als die Infektion des Tumors selbst feststellen liess. In derartigen Fällen wurde die lokale Radiumbehandlung nicht mehr wegen blosser Temperatursteigerung aufgeschoben, und andererseits die schon begonnene Behandlung wegen blossen Fieberanstiegs nicht mehr unterbrochen.

Um Aufschluss darüber zu erhalten, inwieweit dieses Behandlungsprinzip berechtigt ist, und insbesondere um zu ermitteln, welche Rolle die gefürchtete Retention des Exsudates beim Anstieg des Fiebers spielt, beschloss ich, mit Hilfe von zahlreichen Messungen die Körpertemperatur während der Radiumbehandlung bei solchen Fällen zu verfolgen.

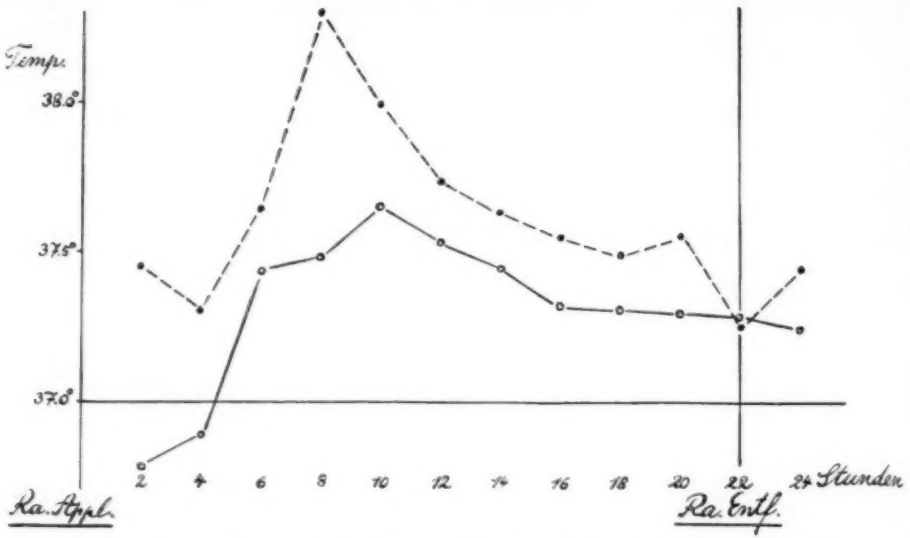
Sulfonamide oder Antibiotica sind im Zusammenhang mit meinen Versuchen nicht angewandt worden, damit sie nicht die Resultate störend beeinflusst hätten. Über den Nutzen der Sulfonamide bei der Behandlung von fiebernden Kollumkarzinomfällen haben wir übrigens in unserem Krankenhaus auf Grund von früher durchgeführten Versuchen keine besonders günstige Auffassung bekommen (KAHANPÄÄ). Bezüglich des Penicillins gehen die Ansichten in gleicher Richtung, wenigstens gemäss den in der Schweiz gemachten Erfahrungen (MERZ).

Ich habe 108 Stundenkurven von ebenso vielen Applikationen gesammelt, alles Fälle, bei denen die Temperatur während der Behandlung mindestens einmal über 37.5° ax. gestiegen war. Die meisten Fälle (71) waren vor der Behandlung fieberfrei, andere (37) hatten schon vor der Applikation erhöhte Temperatur. Die Behandlung wurde in keinem von diesen Fällen früher abgebrochen als ursprünglich bestimmt war.

Die Resultate der Messungen sind in den beigefügten Mittelfieberkurven zusammengestellt, aus welchen die in Frage stehenden Temperaturschwankungen wenigstens in ihren Grundzügen hervorgehen.

Bei denjenigen Patientinnen, welche schon vor der Applikation fieberten, blieb die Temperatur auch während der Behandlung im Durchschnitt höher als bei den vor der Applikation fierberfreien. Als gemeinsamer charakteristischer Zug lässt sich in beiden Stundenkurven feststellen, dass *die bald nach der Applikation beträchtlich gestiegene Temperatur schon während der Behandlungszeit regelmässig zu sinken beginnt, also schon vor Entfernung der Radiumpackungen und des Tampons. Das Fieber braucht also keine Kontraindikation für die Brachyradiumbehandlung zu sein.*

Man kann einwenden, dass in einer derartigen Mittelfieberkurve leicht solche Fälle »verschwinden», welche in anderer Richtung weisen. Dies ist auch in gewissem Masse der Fall gewesen. Unter meinen Fieberkurven befinden sich tatsächlich vereinzelte Fälle, bei welchen die Temperatur ständig bis zum Schluss der Behandlung gestiegen ist. Die geringe Anzahl




*Kurven.* Mittelfieberkurven während der Radiumbehandlung bei Kollumkarzinom.
----●---- vor der Applikation fiebernde Fälle.
——o—— vor der Applikation fieberfreie Fälle.

dieser Fälle konnte jedoch den allgemeinen Verlauf der Kurven nicht beeinflussen. Aus den Kurven geht deutlich hervor, dass *die gefürchtete Retention des Exsudats bei den Temperatursteigerungen während der lokalen Radiumbehandlung von Kollumkarzinomen keine grössere Bedeutung hat*, so naheliegend diese Erklärung a priori auch erscheint, wennschon es angezeigt sein dürfte, im Einzelfalle auch weiterhin diese Möglichkeit zu bedenken.

Worauf beruht nun aber gewöhnlich die bei der lokalen Radiumbehandlung von Kollumkarzinomen so allgemeine Fiebersteigerung? — Eine sichere und erschöpfende Antwort dürfte sich auf diese Frage vorläufig noch nicht geben lassen. Am ehesten könnte man meines Erachtens an folgende Erklärungsmöglichkeit denken.

So vorsichtig die lokalen Vorbereitungen für die Radiumapplikation und insbesondere die Dilatation des Zervixkanals für die intrauterine Applikation auch vorgenommen werden, so lassen sich dabei Zerreissungen des spröden und immer infektierten Tumorgewebes nie ganz vermeiden, wobei sich Blut- und Lymphwege öffnen. Die lokale Behandlung des Kollumkarzinoms gelingt ja niemals ohne mindestens geringere Blutung. In die eröffneten kleinen Gefässe und so in den Kreislauf gera-

ten aus dem neoplastischen Gewebe fremde Stoffe, welche die Fieberreaktion hervorrufen.

Im Hinblick auf die Seltenheit der allgemeinen Sepsis im Zusammenhang mit der Behandlung der anders noch unkomplizierten Kollumkarzinome erscheint es weniger glaubwürdig, dass die Ursache für die in Frage stehenden Fieberreaktionen die aus dem infektierten Tumorgewebe in den Kreislauf gelangten Bakterien wären, jedenfalls nicht diese allein. Mit grösserer Wahrscheinlichkeit sind die Ursache hierfür blutfremde Eiweissstoffe, aber erst weitere Untersuchungen, die bei uns im Gange sind, werden zeigen, ob diese Vermutungen der Wirklichkeit entsprechen.

## ZUSAMMENFASSUNG

Der Verfasser beschreibt ausführlich einen Fall von grossem exophytem Portiokarzinom, welcher vor der Behandlung schon über einen Monat lang gefiebert hatte. Als Ursache für das Fieber liess sich nur die Infektierung des grossen Tumors feststellen. Die Radiumbehandlungen wurden trotz beträchtlicher Fieberreaktionen — bei der I. Applikation ad 40.6° C — vollständig durchgeführt. Nach 5 Jahren ist die Patientin subjektiv und objektiv völlig gesund.

Hiernach hat sich der Verfasser bei der Behandlung der fiebernden, aber sonst unkomplizierten Kollumkarzinomfälle aktiver verhalten. Die Temperaturschwankungen wurden im Verlauf von 108 Radiumbehandlungen verfolgt und die Resultate in zwei Mittelfieberkurven dargestellt. Das am Anfang der Behandlung gestiegene Fieber beginnt regelmässig schon vor der Entfernung der Radiumpackungen und des Tampons zu sinken. Das Fieber an sich braucht also keine Kontraindikation gegen die Brachyradiumbehandlung zu sein.

## SUMMARY

A case of cauliflower epithelioma of the portio is described in which the patient had a fever for four weeks prior to treatment. As no other obvious cause was found the fever was ascribed to infection of the large growth. Although there was a considerable rise of temperature while the patient was under radium treatment with a peak of 40.6° C in conjunction with the first radium application, treatment was continued. The patient has been objectively and subjectively free of symptoms for five years.

This observation led the author to give active treatment also in cases of uncomplicated carcinoma of the collum in which the patient had a fever. The fluctuations of temperature in conjunction with radium therapy were studied in 108 cases. Two curves were constructed showing the average temperatures observed. In the beginning of the treatment there was a rise of temperature which, however, began to fall in all cases before the radium applicators and the tamponade was removed. This observation shows that temperature in itself is no contra-indication for brachyradium treatment.

## RÉSUMÉ

L'auteur décrit en détail le cas d'un grand cancer exophyte du col qui déjà avant le traitement avait été accompagné de fièvre pendant plus d'un mois. Comme cause de la fièvre on ne put constater que l'infection de la grande tumeur. En dépit de

réactions fébriles considérables — atteignant 40.6° lors de la première application — les traitements par le radium furent conduits jusqu'au bout. Cinq ans plus tard la malade est en parfaite santé subjectivement et objectivement.

Depuis lors l'auteur a suivi une ligne de conduite plus envahissante dans le traitement des cancers du col avec fièvre mais sans autres complications. Les écarts de la température ont été notés au cours de 108 traitements par le radium, et les résultats furent visualisés par deux courbes indiquant la moyenne de la fièvre. La fièvre qui s'élève au début du traitement commence à descendre régulièrement déjà avant l'éloignement du radium et du tampon. La fièvre à elle seule n'est donc pas nécessairement une contre-indication au traitement à courte distance par le radium.

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# NEW INSTRUMENTS FOR BRONCHOGRAPHY[1]

by

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The present paper gives a description of a new instrument for anaesthesia of the respiratory tract, and a new instrument for the introduction of the contrast medium into the bronchi. Moreover, it contains some remarks on anaesthesia in bronchography.

In order to obtain good results from bronchographical examinations it is fundamental to prevent cough. A single cough is sufficient to spoil the results of the whole examination.

Coughing is a reflex action, caused by an irritation of neurogenic receptors in the mucous membranes of the laryngo-tracheo-bronchial system. (Receptors are present not only in the largest bronchial tubes, but also in the smaller bronchi.) The impulses are transmitted through centripetal vagus trunks to the vagus nuclei in the medulla oblongata (fig. 3), and from these through centrifugal pathways to the glottis and diaphragm muscles, etc., which are the effectors of coughing.

In order to prevent coughing in spite of the irritation of the abovementioned receptors, which is caused by the contrast medium used in bronchography, it is necessary that the coughing reflex pathway should be temporarily blocked.

The most effective method employed for this purpose is surface anaesthesia of the mucous membranes of the laryngo-tracheo-bronchial system, which desensitizes the receptors of the coughing reflex.

On the other hand, it is usually not sufficient to use only those centrally acting drugs, which reduce the irritability of the coughing reflex path.

If the surface anaesthesia is fully satisfactory, it is not necessary, according to our experience, to administer any centrally acting drugs.

[1] Read at the meeting of the Northern Association for Medical Radiology, Stockholm, June 10—12, 1949; submitted for publication, Jan. 13, 1950.

Furthermore the general condition of the patient is so influenced by these drugs that the bronchographic examination becomes difficult or impossible, particularly if it must be carried out with the patient in the sitting position. On the other hand, it may be advantageous to administer sedatives, *e. g.* phenemal.

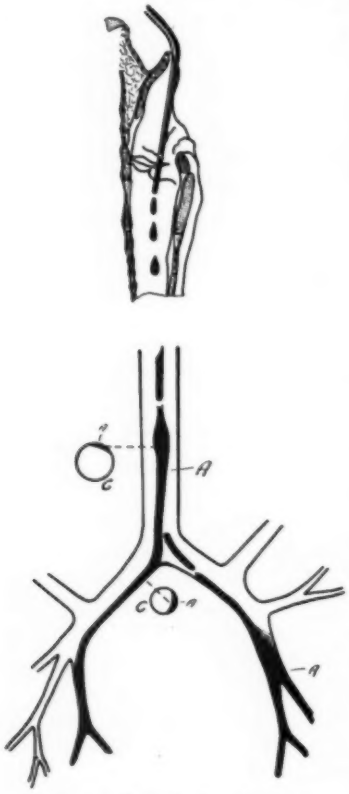


Fig. 1. Description in text.
A = anaesthetic.
C = cross section of the trachea and a main bronchus.

However, surface anaesthesia must comply with the following two requirements: (1) it must be absolutely effective, (2) the risk of complications must be reduced as far as possible at the same time.

1. In order to produce fully satisfactory anaesthesia, the anaesthetic should be spread in a sufficiently thick layer so as to cover the mucous membrane on the whole internal surface of the laryngo-tracheo-bronchial tract. Furthermore, use must be made of a preparation which is satisfactory from the point of view of anaesthesiology. We have used a two per cent solution of Xylocain Special over a period of more than one year, and have found this preparation to be fully satisfactory.

2. The complications occurring in connection with the anaesthesia of the respiratory tract, such as cramps, unconsciousness, etc., are mainly due to the toxic effect of the anaesthetic. It is therefore extremely important to produce fully satisfactory surface anaesthesia with a relatively small quantity of the anaesthetic. Furthermore, use should be made of an anaesthetic of low toxicity. Xylocain has been found to be ideal in this respect.

Surface anaesthesia of the respiratory system is usually produced by injecting the anaesthetic into the larynx by means of a cannula or into the laryngo-tracheo-bronchial system by means of a catheter. In that case, as is seen from figure 1, the anaesthetic does not completely cover the mucous membranes of the laryngo-tracheo-bronchial system if a relatively small quantity of anaesthetic is used. Moreover, the greater

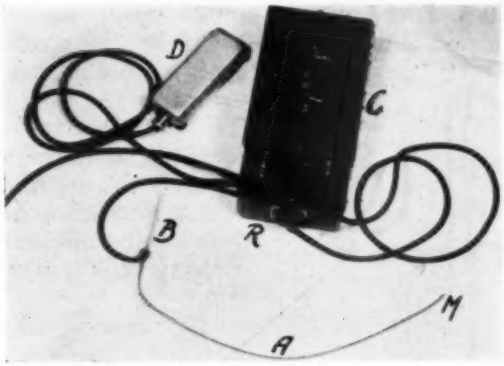


Fig. 2. Instrument for the surface anaesthesia of the respiratory tract.

part of the anaesthetic flows down into the finest ramifications of the bronchi and the alveoli where it is rapidly resorbed owing to the high rate of blood circulation and the large surface of resorption in these parts of the lungs. The fact that a relatively large quantity of anaesthetic is rapidly resorbed constitutes an essential risk of the toxic reactions.

For bronchographic purposes, an easily resorbed, thick-flowing water soluble contrast medium (Viscous Umbradil B) is definitely preferable to iodized oils. If the anaesthetic is injected in the usual way, the quantity of contrast medium remaining in the bronchi is too large, with the result that the contrast medium is diluted, and thus its contrast effect reduced. Furthermore, when the contrast medium is thinned, it readily passes into the alveoli, which is not desirable.

To comply with the requirements outlined above, the author has designed an instrument for superficial anaesthesia of the respiratory system. This instrument spreads the anaesthetic by spraying, see figure 2.

The main part of the instrument is a tube (A in figure 2) which is introduced into the respiratory system, and is provided with an interchangeable nozzle (M in figure 2). The anaesthetic is applied under pressure from the glass container (B in figure 2) by means of compressed air, supplied by a rotary compressor (C in figure 2). The output of the compressor can be varied by means of a rheostat (R in figure 2), so as to regulate the volume flow of anaesthetic per unit time and to some extent also the size of the particles. The compressor is started and stopped by the examiner with the foot-operated switch (D in figure 2).

Since the anaesthetic is dispersed by spraying, the whole internal surface of the laryngo-tracheo-bronchial system is covered with only a thin layer of anaesthetic, see A in figure 3. As the spray jet is sufficiently

strong, the medium-sized bronchial trunks which also contain receptors of coughing reflexes, are likewise blocked by the anaesthetic. On the other hand, the anaesthetic does not pass into the finer bronchial branches and the alveoli.

If the anaesthetic is sprayed by means of this instrument, a quantity of 2.5 to 3 ml is sufficient to produce a fully satisfactory anaesthesia of the laryngo-tracheo-bronchial system.

By spraying Xylocain mixed with an intense water-soluble colour substance (Azorubin) into a glass tube with the same diameter as the trachea and the bronchi, it has been possible to determine an optimum covering of the spray jet.

*Method of application.* The patient is lying on his back, and his head is bent backwards. After the anaesthesia of the pharynx, which may conveniently be produced by means of the instrument described above, a laryngoscope is inserted so as to push the epiglottis to the root of the tongue, see L in figure 3. The instrument can then readily be introduced into the larynx, while spraying the anaesthetic at the same time. During the roentgen examination, the instrument is pushed deeper, while spraying at the same time, through the trachea and the desired main bronchus, and somewhat distally from the bronchus (Fig. 3). A complete surface coating of anaesthetic is obtained if the instrument is introduced at a speed of 2 cm per sec. After the instrument has reached the peripheral bronchial region, it is removed. In about 4 minutes, the anaesthetic effect is fully satisfactory.

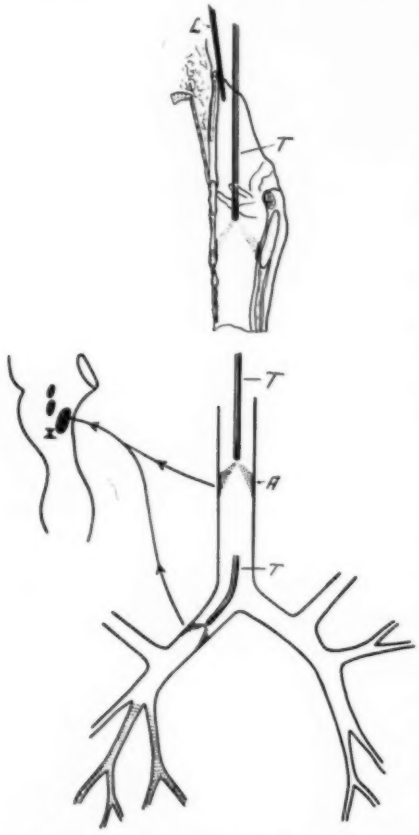


Fig. 3. Surface anaesthesia of the respiratory tract with the instrument in figure 2.
A = anaesthetic.
L = laryngoscope.
T = the tube of the instrument (see A—M in figure 2).

Furthermore, the author has designed an instrument operating in

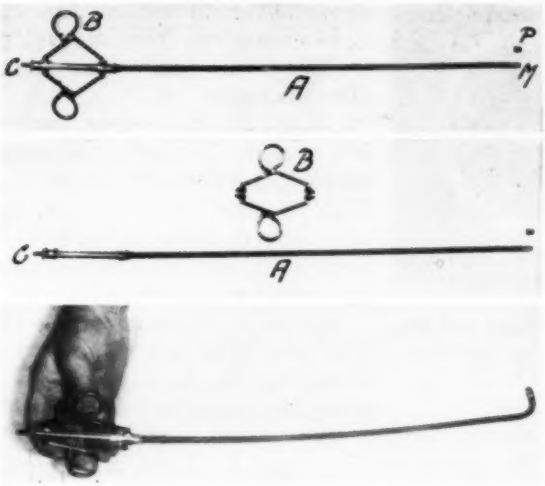


Fig. 4.

Fig. 5.

Fig. 6.

Fig. 4, 5, 6. Instrument for the introduction of the contrast medium into the bronchi.

a fundamentally new principle for introducing the contrast medium for bronchography. (A previously constructed instrument for this purpose has been described by the author in Acta Radiologica, Vol. XXXI, Fasc. 1 31: 1, 1949.)

The instrument is shown in figure 4. That part of the instrument which is introduced into the bronchi (A) is covered with rubber. The detachable nozzle is marked M. The contrast medium is injected through the nozzle C. The shanks B are pivoted on the tube, so that the grip on the shanks need not be released even if the position of the instrument must be changed during the examination. Moreover, the shanks are detachable, see figure 5, and this facilitates the fixation of the instrument by means of a head band, cf. figure 7.

When the shanks B in figure 4 are pressed together, the outer part of the instrument is successively bent up to a maximum angle which is slightly greater than 90 degrees, see figure 6.

The instrument is introduced into the larynx either by means of a laryngoscope in the same manner as the anaesthetizing instrument described above, or during the roentgen examination. This is a very easy procedure since the outer part of instrument is flexible.

As the outer part of the instrument can be bent to a considererable degree, it can be introduced into each bronchial trunk, provided that its lumen is not smaller than the thickness of the instrument. In order

Fig. 7. Head band for the fixation of the instrument in figure 4.

to obtain good results from an examination, it is important from several points of view to apply the contrast medium close to the affected region.

When the instrument has been introduced far enough to reach the region to be examined, it is fixed by means of the head band (Fig. 7) after removing the shanks. This is necessary in order to facilitate the successive application of the contrast medium between the roentgenograms.

By using a special nozzle (P in figure 4), it is also possible to make the excision of tissue sample in that area which has been found to be the seat of a pathological process during the bronchographic examination, particularly for tumour diagnostics. For this purpose, the nozzle C of the instrument is connected by means of a flexible tube to a motordriven suction apparatus (the rotary compressor shown in figure 2 can also be used as a suction apparatus). On account of the vacuum produced in the nozzle, the tissue is drawn into the nozzle by suction. Now if the instrument is slightly moved backwards, a thin slice of tissue is cut off by a knife-edge in the nozzle. The knife-edge is fitted so that it cannot cause lesion while introducing the instrument.

The instruments described in this paper are constructed by the author and manufactured by AB Elema, Stockholm, Sweden.

## SUMMARY

A description is given of a new instrument for surface anaesthesia of the respiratory system, which is specially adapted for bronchography, and a new instrument for the introduction of contrast medium used in bronchography. The latter instrument can also be employed for excision of tissue samples.

## ZUSAMMENFASSUNG

Es wird ein neues Instrument zur Oberflächenbetäubung der Atemwege beschrieben, das sich besonders für Bronchographie eignet, sowie ein neues Instrument zum Einführen von bei der Bronchographie verwendetem Kontrastmittel. Letzteres Instrument kann auch zur Entnahme von Gewebsproben Verwendung finden.

## RÉSUMÉ

L'auteur décrit un nouvel instrument pour l'anesthésie en surface du système respiratoire, et un autre, également inédit, pour l'introduction de la substance de contraste utilisée en bronchographie. Ce dernier peut aussi servir pour les biopsies.

FROM THE CANCER RESEARCH LABORATORIES OF THE RADIOLOGICAL CLINIC, UNIVERSITY OF AARHUS, DENMARK (DIRECTOR: PROFESSOR CARL KREBS)

# HODGKIN'S DISEASE AND PREGNANCY[1]

by

*Jørgen Bichel*

Hodgkin's disease (H. d.) is not a very rare disorder, but nevertheless, on the basis of a study of the literature, it is difficult to get a clear understanding of how a pregnancy is affected by H. d., and vice versa. This may to some extent be explained by the very varying clinical picture and course of H. d. The fact that several women suffering from H. d. have given birth to more than one child during their disease seems to indicate that fertility need not be affected. A critical survey of the literature, in which all cases with uncertain diagnoses and insufficient information have been discarded, has resulted in reports on 57 cases of H. d. complicated by pregnancy, the number of pregnancies totalling 65. An analysis of these cases and of the conclusions to which they have led in the individual cases shows how different the effects of pregnancy on the course of the disease and hence the indications for interruption of the pregnancy have been appraised. At the Radiological Clinic in Aarhus we have had the opportunity to follow the course of H. d. in 81 women, of whom 73 were between 16 and 45 years of age. Eleven of these women became pregnant. Since we have often been asked if interruption of the pregnancy is indicated in such cases, the eleven case histories will be briefly reported and the subject discussed on the basis of these histories and the literature.

## Case Reports

*Case 1.* No. 3094/43. D. M., aged 23, complained of pain in the upper epigastric region, and a large mediastinal tumour was revealed (1943). She was tired and anemic. The tumour regressed during radiation treatment, but exudation appeared on the right side. After thoracocentesis her condition improved. In March 1945 enlarged nodes in the supraclavicular region appeared. *Biopsy:* typical H. d. The roentgenogram

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of the lungs was normal. She received roentgen therapy to the nodes and felt otherwise comfortable. In 1946 she went through a normal pregnancy. According to her own statement she felt unusually well during the pregnancy. Normal delivery of her first boy, 2,900 g, at term. The puerperium was uneventful, and lactation caused no difficulties. She remained well until March 1948 when a tender node developed in the right axilla, and the mediastinal tumour had again increased in size. Treatment with nitrogen mustard gave good effect, and was repeated in January 1949 when enlarged cervical lymph nodes appeared. The patient was well when she was last seen in September 1949. The child healthy, now three years old.

*Case 2.* No. 1324/32. T. R., aged 16, had a mediastinal tumour (1932). She complained of fatigue, cough, and expectoration. The tumour diminished in size during roentgen therapy, but in 1933 the treatment had to be repeated. She then remained well till 1934 when she received roentgen treatment to slightly enlarged lymph nodes in the right supraclavicular region. 1940 greatly enlarged cervical nodes (*Biopsy:* typical H. d.), roentgen treatment, which had to be repeated at intervals to various lymph nodes. In 1942 she had a spontaneous abortion at the third month, which did not seem to influence her lymphogranulomatous condition. In 1944 she went through a normal pregnancy and was delivered of a healthy child. It is difficult to say whether the pregnancy and parturition affected her lymphogranulomatous condition because she was then in an unstable period. Repetition of roentgen therapy at intervals necessary. She died in another hospital in 1947. When last seen, the child was two years old and healthy.

*Case 3.* No. 1348/33. K. O., aged 29; during a normal parturition (1932) she noticed enlarged cervical nodes and stated that they might have developed during the latter part of the gestation period, which ran an otherwise uneventful course. She was admitted to the Radiological Clinic in 1933. *Biopsy* of cervical nodes: H. d. During the years 1933—34—35 roentgen was given to nodes of the neck, left axilla, and the mediastinum. She was able to go about her work in the home unaided. In 1935 she had a spontaneous abortion (*Microscopic examination:* normal for pregnancy, no sign of H. d.). The pregnancy and ensuing abortion did not seem to influence her lymphogranulomatous condition. As late as 1938 she was reported to care for her husband, child, and a farm servant without the assistance of others. During 1939—40 spinal bone destructions with compression myelitis developed. She died in May 1941 at the age of 38.

*Case 4.* No. 1704/46. E. H. R., aged 32, had conceived two years previously (1944). When three months pregnant, she noticed enlarged cervical nodes. They increased slightly in size during the pregnancy, which was otherwise uneventful. Natural parturition at term. Persistent elevation of temperature during the puerperium. *Biopsy* of cervical node about 12 months post partum: H. d. At the same time enlarged mediastinal nodes and infiltration of the right lung were revealed. During 1945—46 roentgen was given to the cervical and mediastinal nodes. Gradually she became rather anemic, and in 1946 she was given a blood transfusion. She was again able to look after her home, and went through another pregnancy without any complications in 1947. She reported to be unusually well during the pregnancy. At full term she gave birth to a normal girl, but felt rather weak post partum. Enlarged nodes developed in the submaxillary region, the neck, and the axillae. She received several courses of roentgen treatment and nitrogen mustard. She is getting on fairly well, and at the last examination in September 1949 she stated she was well and able to care or her house and children. There were no enlarged nodes, but slight enlargement of the spleen and moderate anemia. Her children healthy, two and four years old.

*Case 5.* No. 958/33. T. M. B., aged 26; she had gone through a normal pregnancy and borne a healthy child. She nursed the baby. Four months post partum she noticed a tender node in the left axilla. It rapidly increased in size, but did not cause any discomfort. *Biopsy* five months later: H. d., for which reason she was referred to the Radiological Clinic. There were enlarged nodes in the neck and the supraclavicular fossae. The roentgenogram of the lungs was normal. Following roentgen therapy she was in a fairly good condition. Eighteen months after the first delivery she conceived again, and at once began to feel tired. At third and fourth months pain developed in her left leg, and she re-entered the Radiological Clinic. At that time she was rather weak, looked pale and ill, but there was only slight enlargement of the nodes. Sedimentation rate 110 mm, hemoglobin 60 %, red blood cells 3.62 million. Moderate elevation of temperature. Spray radiation of the whole body with the uterus adequately shielded, 5 r daily, total dose 30 r (150 kv, 3 ma, focus-target distance 150 cm). Her condition improved, but shortly afterwards she was admitted to another hospital, from which it has been reported that her hemoglobin percentage was 32, and that she had felt life. We have further learnt that she died in her home at the seventh month of pregnancy, but we do not know further details.

*Case 6.* No. 878/43. D. K. L., aged 28; para ii. For the past two years she had felt tired; in 1943 enlarged nodes in the mediastinum and the supraclavicular fossae. *Biopsy:* H. d. She was admitted to the Radiological Clinic in April 1943, complaining of pain in the thorax, cough, and fatigue. Sedimentation rate 67 mm/hour, hemoglobin 56 %, red blood cells 3.38 million. Good effect of roentgen treatment to the supraclavicular and mediastinal nodes. July 1943: sedimentation rate 10 mm, hemoglobin 90 %. In January 1945 she received roentgen treatment to the left axilla. October 1945 difficulty in swallowing, for which she was treated with roentgen to the nodes around the cardia, in two anterior fields, 900 r to each, with good effect. In the beginning of 1946 febrile periods and itching of the skin, which subsided after roentgen treatment to the cervical nodes in May 1946. Another course of roentgen was given in February 1947, and at that time her general condition was fairly good. October 1947: sedimentation rate 21 mm, hemoglobin 100 %; roentgenogram of the lungs: nothing abnormal. In 1948—49 she went through a pregnancy, during which she felt quite well. In August 1949 she gave birth to a girl, six weeks prematurely. The child, 2,100 g, had cleft lip and palate. No exacerbations of H. d. post partum. At a follow-up examination in November 1949 she stated to be well, not very tired, and able to attend to her domestic duties; yet she complained of some generalized itching of the skin. There were hazelnut-sized nodes in both axillae, but otherwise no glandular enlargement. No febrile periods, but the sedimentation rate was still 66, hemoglobin 70 %, red blood cells 3.10 million. The roentgenogram of the lungs showed no signs of progression.

*Case 7.* No. 2486/35. A. M. J., aged 40. In January 1935 she noticed enlarged nodes in the neck. The enlargement developed within a few hours and disappeared again in the course of some days; afterwards she felt well. She conceived one month later. During the pregnancy she had frequent attacks of nausea and vomiting and felt very tired. During the pregnancy she was examined in another hospital, where enlarged nodes of the mediastinum were revealed. At full term she was delivered of a girl, 3,100 g. During the puerperium there was persistent elevation of temperature. She was admitted to the Radiological Clinic in November 1935 with high, oscillating temperature and numerous enlarged nodes in the neck and a large mediastinal tumour. *Biopsy:* typical H. d. During the following years she was treated at intervals at the Radiological Clinic with roentgen therapy to various nodes and the mediastinum, and later when destructive areas in

the spinal column developed, also to these. During the first period of this time she was fairly well, but later she had increasing discomforts from the spinal affection. She died in her home in October 1938.

*Case 8.* No. 12/31. B. A. L., aged 23. In 1930 she was referred to the Radiological Clinic for persistent enlargement of the nodes of the neck, which did not otherwise affect her general condition. Slightly enlarged hilus nodes were also revealed. The cervical nodes subsided and reappeared several times. *Biopsy* 1932 showed H. d. During each of the years 1930—35 she was given roentgen therapy to the nodes and the mediastinum. She was fairly well during this period and was mostly able to attend to her work. In 1936 she became pregnant. At the second month a vaginal hemorrhage occurred, and curettage was performed. *Microscopic examination* showed fetal remnants, but no signs of H. d. The pregnancy and ensuing abortion did not induce exacerbations of her lymphogranulomatous condition, but as she complained of pain in the spinal column, it was necessary to give her courses of roentgen therapy in each of the years 1936—38. In spite of repeated roentgen examinations of the spine a destruction in the fourth lumbar vertebra was not visible until May 1938. During these years some progression of the pulmonary changes had occurred. In periods she was very tired and debilitated, but as late as December 1938 when she was seen for the last time, she stated to be able to look after her home unaided. In her home the patient went downhill rapidly and died in March 1939.

*Case 9.* No. 755/33. D. A., aged 28. Enlargement of cervical nodes was noticed in 1933, and the patient complained of increasing fatigue. In April 1933 the patient was admitted to the Radiological Clinic for enlarged mediastinal nodes. *Biopsy* 1933: lymphadenitis, H. d.?; 1934: typical H. d. During each of the years 1932—35 she was given roentgen, partly to cervical and axillary nodes, partly to the mediastinum, and her condition was fairly good. In July 1935, she was found to be two months pregnant, but was otherwise well and in good general condition. No enlarged nodes and no mediastinal tumour were found. Sedimentation rate 8, hemoglobin 83 %. She had had slight nausea, but otherwise no discomforts from the pregnancy. Abortion was induced without complications. *Microscopic examination:* normal for pregnancy; no signs of H. d. No exacerbations in relation to the abortion. She remained well and needed no roentgen therapy until April 1936. During 1936 she was able to carry on her work almost without interruptions. In 1937 gradually incapacitating pain began to develop in the lumbar region. In June 1938 destructions in the twelfth dorsal vertebra was revealed. She died in her home in October 1938, 5½ years after the onset of the disease.

*Case 10.* No. 663/30. H. Ø., aged 20, was referred to another hospital for enlarged cervical nodes. *Biopsy:* H. d. The patient is still alive, free from recurrences, 20 years after, and as the histologic specimen cannot be produced, the pathologist's report is cited here because the histologic picture does not correspond to that of a fully developed Hodgkin's granuloma: »The node contained incipient formation of granulation tissue with hypertrophy of the reticulo-endothelial cells with scattered large, irregular cells, rich in plasma and with an irregular nucleus or two or three nuclei. Everywhere large numbers of eosinophilic leukocytes and a few polynuclear neutrophils. Typical large Sternberg-Reed cells were, however, absent. No necroses.» — The histologic examination was carried out by an experienced pathologist. The condition was interpreted as H. d., and the patient was referred to the Radiological Clinic. There were several enlarged nodes, the size of a hen's egg, in the neck, to which roentgen was given. In 1931 some persistent smaller nodes appeared; the roentgen therapy was repeated, and since then the patient has remained well. In the course of the years she has reported

at the Radiological Clinic for follow-up examinations many times, last time in September 1949. There has been no glandular enlargement, and her blood counts have remained normal.

In 1941 she went through a normal pregnancy with natural parturition at term. Lactation was continued for four months. Another normal pregnancy and parturition in 1945. The children are now eight and four years, healthy.

*Case 11.* No. 1754/35. M. H. S., aged 21, was admitted to the Radiological Clinic in 1935 with enlarged cervical nodes, the size of walnuts, slight elevation of temperature, intermittent sweats, and cough. Roentgen examinations of the lungs showed a fairly large mediastinal tumour. *Biopsy* of cervical nodes: typical H. d. She was treated with roentgen to the cervical nodes and the tumour with good effect. During the following year the glandular enlargement and the tumour disappeared completely. In 1937 the patient married and went through a normal pregnancy with natural parturition at full term. The puerperium and lactation normal. In 1938 she had another normal pregnancy. She has been followed up at regular intervals, and since 1935—36 she has remained completely well (now 14 years after the onset of the disease), and no objective signs of the disease have been demonstrated. Her blood counts have been within normal limits. Her two girls, now eleven and twelve years old, are healthy and have shown no signs of H. d.

In addition to these eleven patients who must all be supposed to have conceived after the onset of H. d., three women have dated their first symptoms of H. d. from a pregnancy. They have, however, been excluded because the information obtained is somewhat uncertain. It has sometimes been pointed out that in a strikingly large number of instances the first symptoms of H. d. have been noticed during pregnancy. However, the obvious source of error exists that the attention directed to subjective sensations and objective symptoms is intensified during pregnancy, which may explain why glandular enlargement, which has so far passed unnoticed, is observed.

In the literature fairly detailed reports of 46 women with typical H. d. complicated by pregnancy are available; together with the eleven cases presented here, it makes a total of 57, in whom 65 pregnancies have occurred, of which 42 went to term. In three instances the child was stillborn; three terminated in premature delivery, and twelve in spontaneous abortion; abortion was induced in eight instances, and there was one case of cesarean section (due to marked edema of vulva, viable child, KLAWANS, 14). The majority of the deliveries have been natural without any obstetrical complications, and the same applies to the puerperium. No cases of severe post partum hemorrhage have been reported. In some cases the condition has aggravated during the pregnancy. However, especially post partum, some cases seem to have been accelerated, with rapidly increasing glandular enlargement, persistent elevation of temperature during the puerperium, and fatal outcome shortly after parturition. It is very difficult to evaluate the influence of pregnancy on H. d. because the latter is extremely capricious,

so that its course cannot be predicted. Acute exacerbations are frequent and will therefore also occasionally occur during a gestation period, and hence it may be doubted that all the exacerbations met with in the cases reported can be attributed to the pregnancy. At least, numerous cases are known in which it has been absolutely impossible to detect any accelerating effect on the accompanying H. d., and in some instances the patients have even maintained that they felt much better than usual during the pregnancy. It is impossible to decide whether patients who have gone through a pregnancy will die earlier than they would otherwise have done. But it is worthy of note that, according to the reports available, many mothers with H. d. have survived for long periods after both one and two normal deliveries, not infrequently till the children have grown up (GILBERT, 9).

Judging from the facts that H. d. is more frequent in men than in women, and that, on the whole, the disease runs a comparatively less severe course in women, especially of the childbearing age, it has been supposed that the onset and course of H. d. may to some extent be influenced by female hormones. Hormonotherapy has also been attempted, but generally with a negative result. In this connection it is of interest to note that only one case (Case 5 reported here) of H. d. complicated by pregnancy has terminated fatally during the gestation period.

Only one case on record can with some degree of certainty be interpreted as congenital H. d., transmitted during intrauterine fetal life (PRIESEL and WINKELBAUER, 22). Two other cases are uncertain (v. BRAITENBERG, 4: H. d. was diagnosed in a child, aged one month, but not in the mother; LUETKENS, 16: H. d. was diagnosed in a child, aged 33 months, whose mother had died after *clinical* signs of H. d.). Incidentally, as far as the fate of the children is concerned, little information is available, but in some cases it has been possible to follow them till they reached adult life (GILBERT, 9) without finding signs of H. d. A certain hereditary disposition is, however, likely to be present. In some of the cases in which abortion occurred or the pregnancy was interrupted, the placentas and the fetuses have been examined histologically, but no signs of H. d. have ever been found.

A much larger number of observations is, of course, necessary before it is possible to clarify the influence of pregnancy on H. d., and vice versa, but on the basis of the observations so far obtained it must, however, be justified to conclude:

1) That conception frequently occurs in women suffering from H. d.

2) That, from an obstetric point of view, the pregnancy, parturition, and puerperium run a normal course in the great majority of cases.

3) That acute exacerbations of H. d. are at any rate not essentially

more frequent during the pregnancy than could be expected spontaneously.

4) Only one case is on record, in which the mother died during the pregnancy.

5) Only one case has been reported, in which it can be said with a reasonable degree of certainty that intrauterine transmission from mother to child took place.

6) Generally, there will be no indication for interruption of pregnancy in patients with H. d.

**Acknowledgement**

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## SUMMARY

On the basis of information of 65 pregnancies in 57 patients with Hodgkin's disease it is concluded that, in general, there is no indication for interruption of pregnancy in such patients. In 81 women, treated for Hodgkin's disease at the Radiological Clinic in Aarhus, conception occurred in eleven. Three of these patients have gone through two normal pregnancies, four through one, thus making a total of ten children. Hodgkin's disease was not found in any of the children. In one case the pregnancy terminated in the death of the mother at seventh month (incidentally, the only known case with fatal outcome during pregnancy). Spontaneous abortion occurred in two patients, and the pregnancy was interrupted in one. Apart from the one case, in which the patient died during the period of gestation, the pregnancies do not seem to have caused acute exacerbations of the lymphogranulomatous condition or accelerated its development.

## ZUSAMMENFASSUNG

An Hand von Auskünften über 65 Schwangerschaften bei 57 Patientinnen mit Morbus Hodgkin wird gefolgert, dass bei diesen Kranken im allgemeinen keine Indikationen für eine Unterbrechung der Schwangerschaft vorliegen. Von 81 Frauen, die in der Radiologischen Klinik in Aarhus wegen Morbus Hodgkin behandelt wurden, wurden 11 schwanger. Drei dieser Patientinnen haben zwei normale Schwangerschaften durchgemacht, vier Patientinnen eine, was eine Gesamtzahl von zehn Kindern gibt. Bei keinem der Kinder wurde Morbus Hodgkin gefunden. In einem Falle endete die Schwangerschaft mit dem Tode der Mutter im siebenten Monat (durch einen Zwischenfall, der einzige bekannte Fall von tödlichem Ausgang in der Schwangerschaft). Spontaner Abort trat in zwei Fällen ein, und in einem wurde die Schwangerschaft unterbrochen. Abgesehen von dem einen Falle, wo die Kranke während der Schwangerschaft starb, scheinen die Schwangerschaften kein akutes Aufflammen des lymphogranulomatösen Zustandes gegeben und seine Entwicklung nicht beschleunigt zu haben.

## RÉSUMÉ

D'après les renseignements obtenus sur 65 grossesses chez 57 femmes atteintes de la maladie d'Hodgkin l'auteur conclut qu'en général il n'y a pas d'indication à interrompre

la gravidité chez ces malades-là. Sur 81 femmes traitées pour un Hodgkin à la clinique Radiologique d'Aarhus onze devinrent enceintes. Trois d'entre elles ont mené à terme, chacune, deux grossesses normales, et quatre une grossesse unique, ce qui donne un total de dix enfants. Chez aucun de ces derniers on ne retrouva la maladie. Dans un cas la grossese aboutit à la mort de la mère à sept mois (soit dit en passant, c'est le seul exemple connu d'issue fatale pendant la grossesse). Il y eut une fausse-couche spontanée chez deux malades, et chez une autre un avortement provoqué. Mis à part le seul cas où la malade mourut pendant la période de gestation, les grossesses ne semblent avoir ni causé d'exacerbation aiguë de la lymphogranulomatose, ni accéléré son développement.

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# PHYSICAL ASPECTS OF THE ROENTGEN RADIATION FROM A BERYLLIUM WINDOW TUBE OPERATED OVER THE RANGE 2—50 K.V.P. FOR CLINICAL PURPOSES[1]

by

*W. A. Jennings*, M. Sc., A. Inst. P.

## PART I

## INTRODUCTION AND EXPERIMENTAL PROCEDURE

### 1. Introduction

Publications relating to »low voltage» Roentgen radiation have generally been concerned with the use of one of two types of equipment, namely, the CHAOUL and PHILLIPS designs.[2] As these units are operated at fixed settings within the range 40 to 60 K.V., there is a gap in the voltage range in use between these values and those generally employed in Grenz ray therapy, the latter ranging from 4 or 6 to 12 K.V., though values up to 25 K.V. have been used at one Centre.

There is a large number of papers discussing the use of the above equipments, but only a very small proportion is concerned with the physical aspects of the radiations. For example, with regard to the Chaoul type, a series of papers by CHAOUL (1934—5), the measurements made by MAYNEORD (1936) and Chaoul's more recent book (1944) cover the ground, whereas the physical data relating to the Phillips equipment may be found in papers by LAMERTON (1940), BRAESTRUP and BLATZ (1940), and QUIMBY and FOCHT (1943). The lower voltage range covers the Grenz rays introduced by BUCKY (1927, 1929), the physical founda-

[1] Submitted for publication Jan. 8, 1950.

[2] These techniques are generally termed »contact therapy» on account of the very low focal—skin-distances concerned.

tions of which have been discussed by KÜSTNER (1927—8), GLASSER and PORTMANN (1928), and also GLASSER (1932). More recently, voltages up to 25 K.V. have been used by EBBEHÖJ (1937).

The gap in the range of voltages generally employed for therapeutic purposes was due to the wall absorption of the longer wavelength Roentgen rays of the tubes designed to withstand higher voltage operating conditions, whereas the fragility of the Lindemann window (mechanically and thermally) used for Grenz ray transmission formed the limiting factor at the lower voltages. However, with the development of the beryllium window tube (CLAUSSEN and SKEHAN, 1942; MACHLETT, 1942; ATLEE 1943) in America, it became possible to produce a more robust source of low voltage radiation, covering not only the former Grenz ray voltage range, but one rising continuously up to any K.V. desired. Thus. by means of a suitable voltage generator the entire range from 4 to 50 K.V. became available for application, and recently TROUT and ATLEE (1942—3—7) have described the use of such tubes at voltages up to 1,000 K.V., windows up to 3 mms. thickness of beryllium being used.

Very little physical data relating to the radiation from beryllium window tubes has yet been published, chiefly owing to the difficulties which arise in the relevant measurements of radiations of these qualities, and to the high intensities usually involved. Thus, apart from some theoretical work of ROGERS (1945—6, 1947), who calculated certain intensity-wavelength distributions based on some work of KRAMERS (1923), the only available data has been put forward privately on a tentative basis by BRAESTRUP (1945—6), BIRKMAN (1948) and EBBEHÖJ (1948). The first two authors provide certain output data, and the absorption in aluminium. but confine themselves to measurements at 50 K.V. On the other hand Ebbehöj's work briefly covers the entire range 6—50 K.V.P. with filtrations up to 0.5 mm. Al., together with some depth dose curves in special waxed paper. For similar reasons, the following work must be considered provisional pending the construction of a suitable standard chamber by the National Physical Laboratory.

Recently, at the National Bureau of Standards in America, a standard air chamber has been used by DAY and TAYLOR (1949) to measure the absorption in air of Roentgen radiation from beryllium window tube operated down to 10 K.V., and also by DAY (1948) to calibrate various types of thimble chamber including the Victoreen Nylon chamber designed for use with the soft rays in question. However, the standard air chamber is not suited to depth dose measurements, and the Nylon Victoreen is markedly wavelength dependent at Grenz ray qualities (see § 4 and § 6).

The object of the present work has been to extend that carried out by EBBEHÖJ by varying all the factors over much wider ranges, and

thence by analysis of the data obtained, to determine the basic factors upon which the best therapeutic technique could be evolved.

## 2. Scope of the Present Work

Before undertaking this work, it was evident that the following possibilities, for use in treatments, arise:

(1) Very high outputs when high K.V.'s (50) and tube currents (50 mA) are used with low filtration.

(2) The continuous variation of the radiation quality, and hence penetration of the radiation, enabling one to make the most appropriate choice for each case.[1]

(3) The wide variation of treatment time for any given radiation quality by alteration of the tube current. In practice, this variation covers a range of between 20 to 1 and 10 to 1, depending on the K.V.P. used.

(4) The possible variation of the shape of the depth dose curve for a given »half-value-depth» in tissue by the alternative use of high K.V.'s combined with low filtration, or of low K.V.'s with high filtration. These two approaches are found to lead to opposing advantages, as will be discussed in a later section. (Part II, § 11 (e).)

The extent by which the several factors can be varied with the equipment used may be gauged from the following data:

(i) The applied voltage may be varied continuously from 0 to 50 K.V.P.

(ii) The tube current may be varied continuously from 0 to 50 mA.

(iii) The maximum filtration used at any given K.V.P. is governed by the transmitted output rate, thicknesses up to 3.2 mms. of aluminium being found practicable at 50 K.V.P.

(iv) The focal—skin-distance (F.S.D.) may be varied from a minimum of 3.5 cms. upwards, though a value of 10 cms. has been chosen as a convenient practical basis.

(v) The diameter of the irradiated field may be varied up to a maximum equal to 4/5ths of the F.S.D., but diameters in excess of one half the F.S.D. are not recommended on account of the intensity distribution found.

(vi) The output of the tube at 10 cms. F.S.D. has been found to vary from 0 up to a maximum of some 60,000 roentgens per minute.

[1] EBBEHÖJ (1937) made his choice between different radiation qualities in accordance with the thickness of the regions treated.

(vii) The half-value-layer (H.V.L.) in aluminium has been found to vary up to ~ 2.0 mms., whereas the half-value-depth (H.V.D.) in »tissue-like» wax varies from 0.14 mm. up to 15.8 mms. at 10 cms. F.S.D. (or up to 30 mms. at 70 cms. F.S.D., — a total range of over 200 to 1).

The fact that the K.V.P., the tube current and the external filtration are independently, as well as continuously, variable over such *wide* ranges enables one to adjust the shape of the depth dose curves to some extent.

The *quantity* of the radiation has been measured in terms of roentgens, the difficulties involved in obtaining the correction factors to apply to the instrument readings, and in dealing with the very high dose rates being discussed below.

The *quality* of the radiation has been measured in terms of the half-value-layer in aluminium, though it has only been so specified for comparison purposes. A more useful attribute of a related character has been adopted for the present work, namely a measure of the *»penetration»* of the radiation into tissues, or for measurement purposes, »tissue-like» wax. Thus, the depth at which the dose rate is reduced to 50 % of that at the surface, or »half-value-depth» (H.V.D.) has been chosen as a basis, though a fuller specification includes also the depth at which 90% of the surface intensity has been absorbed (*i. e.* the 10 % depth). Terming the ratio of the 90 % absorbed depth to the 50 % absorbed depth the »fall-off» ratio (F.O.R.) it is evident that the combined use of the H.V.D. and F.O.R. for a particular quality offers not only a fuller description than the H.V.L. in aluminium, but a more useful one in practice. An earlier choice of the 75 % absorbed depth only was dropped in favour of the above system when it was found possible to vary the F.O.R. for a given H.V.D.

The H.V.D., as a measure of penetration, includes both the effect of the inverse square law fall in dose rate and that of scatter contributions, thereby becoming dependent on both F.S.D. and field area variations. This is, however, an advantage for the »penetration» thus automatically embraces the effect of these two variables in addition to that of the K.V.P. and filtration.

All *filtration* employed consists of aluminium sheets or foils, the use of a single filter material eliminating any further variables which would only introduce discontinuities into the resulting data. The thicknesses employed were 3.22, 1.06, 0.56, 0.25, 0.10 and 0.05 mms.[1] The fractional values of the thicker filters need not prove a limitation, for the measured results have been interpolated graphically to cover all filter thicknesses.

[1] Pure aluminium foil of the three thinner gauges was kindly supplied by Fisher's Foils Ltd.

### 3. Equipment Used for the Production of Roentgen Rays

(a) The *roentgen ray tube* used was a Machlett AEG-50-T shockproof tube. This tube has a nominal inherent filtration of 1.0 mm. beryllium; a focal spot size of 5.0 mms. square in projection which allows of a maximum rating of 50 mA at 50 K.V.P. under continuous operation.

(b) The *apparatus* required to energise the above tube has been provided[1] in a provisional form for the purpose of the present physical investigation, and for preliminary clinical work. The high tension (half-wave) transformer incorporated provides unidirectional pulsating tension to the Roentgen ray tube via a single flexible shockproof cable, and is oil-immersed, together with the rectifying valve and valve filament transformer in a steel tank. The tube stand is arranged for maximum tube mobility, and in addition to the synchronous timer, the control panel incorporates means of adjusting all the relevant variables over the full ranges. The design of this equipment will not be further discussed at present in view of its provisional nature.

### 4. The Problem of Output Measurements

Both the quality, and the quantity, of the radiations concerned in the 2—50 K.V.P. range lead to considerable measurement difficulties, particularly as regards translating the instrumental readings into roentgens per minute at all operating conditions.

The problem had already been encountered by KÜSTNER (1927—8) and GLASSER (1928) when measuring Grenz rays at relatively low outputs, and chambers based on these designs were used by EBBEHÖJ (1937). The Siemens Company, having produced Grenz ray equipment, also produced the necessary apparatus for output measurements down to 7 K.V., and it is this instrument which has been used by CHAOUL (1944, p. 77) in the physical measurements relating to his contact therapy technique.

In America, the first chamber used by TROUT and ATLEE (1942—3) to measure the output of a beryllium window tube was of the Victoreen thimble type with bakelite walls. Subsequent work by VICTOREEN, ATLEE and TROUT (1945) showed that the readings at the lower K.V.'s were at least 50 % low on account of the chamber wall absorption. Details of a beryllium wall chamber are given, and more recently DAY (1948) discusses the use of the Victoreen thimble chamber with Nylon walls 0.005 ins. in thickness. In both instances, however, the correction factors which have to be applied to the scale readings increase rapidly in the Grenz ray region. (See Fig. 3 § 6 (a).)

[1] The author wishes to express his thanks to Messrs. Watson & Sons (Electro-Medical) Ltd., for the continued loan of the complete Unit.

The type of chamber described by TAYLOR and STONEBURNER (1932), or more recently, the »mesh» chamber described by QUIMBY and FOCHT (1943) for the measurement of Phillips contact therapy radiation should prove, if suitably adapted, more practical from the standpoint of absorption measurements in addition to air dose rates. It was by means of a chamber design based on the two latter types mentioned that BRAESTRUP (1945—6) made the output measurements to which reference has previously been made.

The present measurements were made by means of the Siemens instrument, which though not previously used for measurements with beryllium window tubes, was found to be well suited to the task both as regards quality and quantity, though certain modifications were introduced for measurements below 7 K.V.P., and allowances for ionic recombination losses had to be made for dose rates in excess of ~ 2,000 roentgens per minute.

### 5. Apparatus Used for Output Measurements

The Siemens Universal Dosemeter was designed to measure either the dose rate, or to integrate the total dosage received over a given period of time. The former is obtained directly by an electrometer measurement of the potential drop occasioned by the flow of the ionization current, without amplification, through a resistance; whereas for the latter, the electrometer is utilised to measure the rising voltage, caused by the ionization current, of an insulated measuring condenser.

At dose rates below ~ 2,000 r/min., the three calibrated ranges apply as follows:

full scale deflection on dose rate scale: 60 r/min.
» » » on first integrating dose scale: 160 r
» » » on second » » » : 800 r

It will be seen at once that, apart from the measurement of total doses delivered, the latter two ranges offer means of high dose rate measurement, the progressive electrometer deflection being timed with a stop-watch.

Two different types of ionization chamber have been used in the present measurements. Both of these, the »phantom chamber» and »Grenz ray chamber» are stated by the makers to be wavelength independent (within 2 %) down to 7 K.V. and to be fully saturated up to dose rates of 1,000—1,200 r/min. at the constant chamber voltage of 200 volts. Fig. 1 shows both these chambers, the »phantom» one being used to measure depth dosage in »tissue-like» wax.[1]

As in the design of the chamber used by BRAESTRUP (1945—6) these

[1] See § 7.

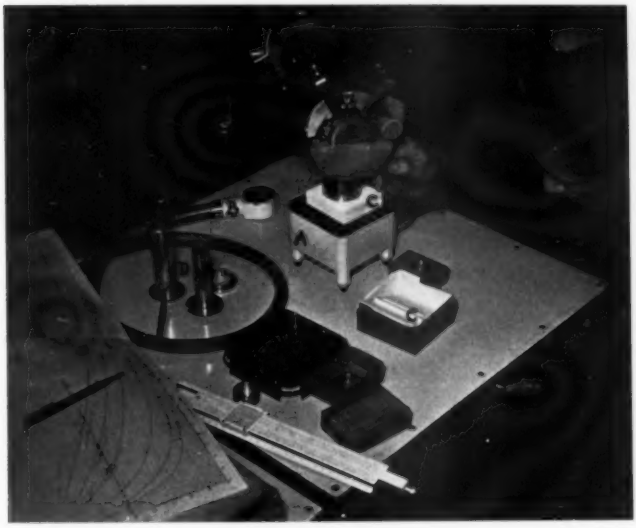

Fig. 1. Apparatus used for Output Measurements.
A: Siemens »Phantom» chamber. D: Treatment applicators.
B: Siemens Grenz ray chamber. E: Roentgen-ray tube.
C: Slabs of »tissue-like» wax.

chambers employ extremely thin films of styroflex coated with graphite as the upper transmission electrode.

The *phantom chamber* (Fig. 1, A) consists of a cup-shaped chamber embedded in the centre of a cylindrical volume of »tissue-like» wax of some 10 cms. diameter. The upper electrode consists of a thin styroflex film coated with graphite on the inside, 1.3 cms. in diameter, and situated in the same plane as the wax surface.

The lower electrode (also graphited) is of 5 mms. diameter and is spaced 5 mms. below the upper one. The latter is insulated by natural amber.

The *Grenz ray chamber* (Fig. 1, B), intended for use at radiation qualities at which scatter contributions are negligible, does not include any surrounding wax, but is built into a closed cup with a limiting diaphragm at its surface, the 7 mms. diameter aperture of which is smaller than the area of either electrode below, thereby producing an effective air volume within surrounding air at the sides. The upper electrode consists of a very thin graphited film 0.03 mm. thick, spaced 5 mms. above the fine wire network which forms the other electrode.

Thus, with the two chambers, readings of output at voltages down to 7 K.V. can be obtained, scatter contributions being included when present.

*Modifications introduced to measure very soft radiation*

At qualities below 7 K.V., the styroflex absorbs much of the radiation, so that it was decided to replace this electrode in the Grenz ray chamber by a mesh of very fine nylon threads (2 mms. spacing) rendered conducting by means of dilute colloidal graphite (Aquadag). The chamber thus produced is similar to that devised by QUIMBY and FOCHT (1943), who used three planes of silk threads soaked in indian ink, the threads being a few millimetres apart, and the planes spaced by 1 cm.

## 6. Calibration of the Output Measuring Apparatus

(a) *Quality Dependence*

The combined use of four chambers was employed to determine the scale-reading multiplying factors to derive outputs in roentgens per minute at all qualities. The derivation of these factors against quality or penetration involves the concurrent measurement of the latter expressed respectively in terms of H.V.L. in aluminium and H.V.D. in »tissue-like» wax.[1] As »tissue» penetration was considered to be of greater practical interest, the initial calibrations were all based on this material, though aluminium H.V.L.'s have since been included for comparison purposes. It is found, however, that except at Grenz ray qualities the relation between H.V.D.'s in tissue and H.V.L.'s in aluminium depends slightly on the K.V.P. concerned (see PART II, § 12 (b)).

Thus, over a wide range of K.V.P.'s and filtrations, a series of measurements was made to determine the H.V.D.'s in »tissue-like» wax corresponding to the known settings.[2] Further, keeping to one F.S.D. (10 cms.), the irradiated field diameter was varied to determine the penetration at which scatter contributions became insignificant, thus indicating whether the phantom chamber or Grenz ray chamber would provide the more accurate data, a choice which thus depends on both the K.V.P. and the filtration.

Inconsistencies, later shown to be due to ionic recombination losses at dose rates in excess of ~ 2,000 r/min., were intitially removed by the use of low tube currents only in all measurements.

With the data collected in this manner, calibration became possible by comparing the readings of the different chambers as follows:

[1] These are based on relative readings only.

[2] See PART II, § 10.

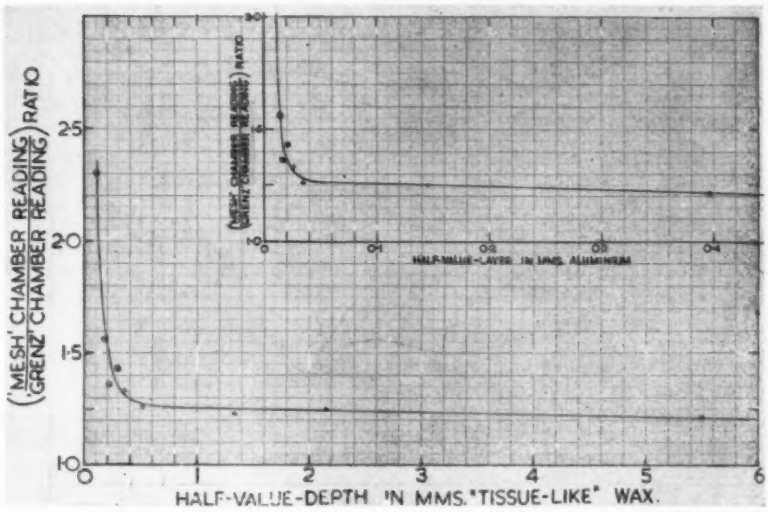


Fig. 2. Calibration of Siemens Chambers against radiation quality.

At each of a series of relatively low penetrations (*i. e.* H.V.D.'s) the upper electrode of the Grenz ray chamber was changed from graphited styroflex film to the nylon mesh and measurements made without altering any tube setting. The ratio of the scale readings (See Fig. 2) forms a measure of the graphited film absorption. This is seen to be marked for penetration less than 0.6 mm. H.V.D. (*i. e.* a quality of 0.04 mm. Al. H.V.L.) whereas the ratio falls very slowly for penetrations between 0.6 and 6 mms H.V.D. The ratio towards which the graph is asymptotic is greater than unity owing to small geometrical differences, and the field penetration at the front in the mesh design.

Since the phantom chamber can be used for penetrations down to 2 mms. H.V.D., the higher penetration portion of the graph in Fig. 2 can be used as a basis for extrapolation up to the maximum penetration concerned, namely 15.8 mms. H.V.D. (a quality of 1.93 mms. Al.) at 50 K.V.P. Fortunately, this latter figure just exceeds the minimum H.V.L. in Al. down to which a Victoreen bakelite thimble chamber can at present be calibrated by the National Physical Laboratory, thereby fixing one point on the graph by means of a Standard air chamber.

In this way, the extended curve of Fig. 2 becomes a calibration curve, a new basic ordinate 1.0 being introduced from the National Physical Laboratory calibration by comparing the readings of the standardised

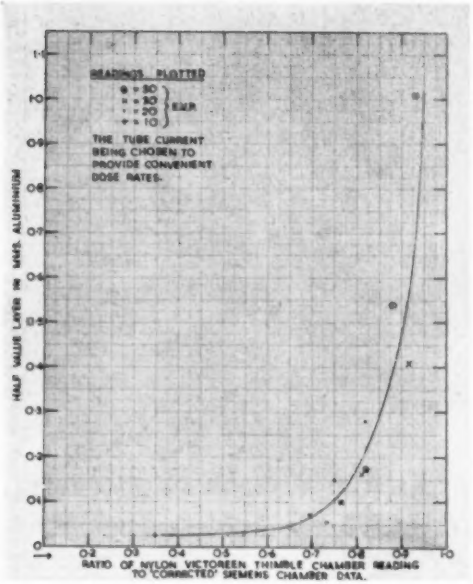
READINGS PLOTTED
EXP.
THE TUBE CURRENT BEING CHOSEN TO PROVIDE CONVENIENT DOSE RATES.
HALF VALUE LAYER IN MMS. ALUMINIUM
RATIO OF NYLON VICTOREEN THIMBLE CHAMBER READING TO 'CORRECTED' SIEMENS CHAMBER DATA.

Fig. 3. Calibration of a Victoreen Nylon chamber against the Siemens chambers.

Victoreen with that of the phantom chamber under the appropriate tube settings.

This somewhat complex approach has recently been tested by measurements with the new Nylon chamber Victoreen. Using radiations over a wide range of qualities, and assuming the previously calibrated output to be correct, correction factors were derived for use with the nylon Victoreen, all measurements being made at dose rates between 300 and 460 r/min. The results, plotted against H.V.L. in Al. are shown in Fig. 3. This graph compares well with that obtained by DAY (1948) though the latter used constant potential in contrast with the present pulsating tension, and he has taken the multiplying factor at 100 K.V. with 0.22 mm. Cu. filtrations as unity. However, it is noted that in Day's results a marked increase in the factor occurs below 15 K.V. under zero filtration. In the present work, the bend in the graph occurs at $\sim$ 0.06 mm. Al. H.V.L. which corresponds to $\sim$ 25 K.V.P. with no filter.

Further, pending the construction of a suitable Standard air chamber for these radiation qualities, the best confirmation of the accuracy of the above calibration lies in the »smooth» relationships existing over very wide ranges among the many variables concerned in different groupings, as will be seen below (PART II). Apart from the common calibration difficulties the great advantage of the Siemens chamber designs over

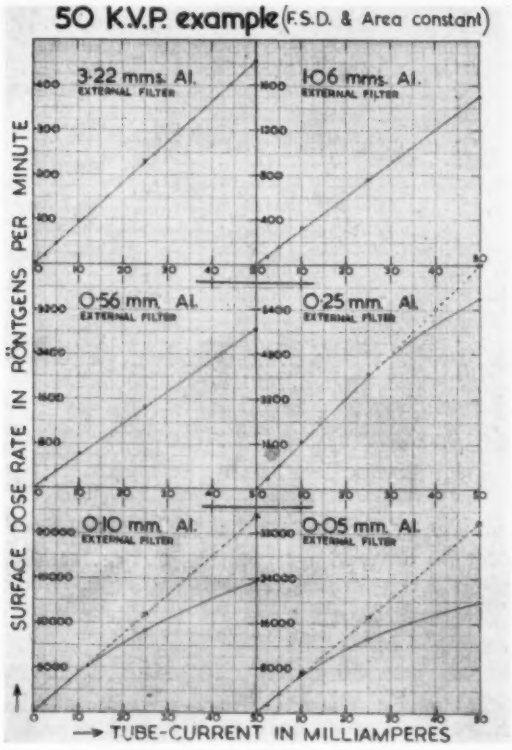
50 K.V.P. example (F.S.D. & Area constant)
3·22 mms. Al. EXTERNAL FILTER
1·06 mms. Al. EXTERNAL FILTER
0·56 mm. Al. EXTERNAL FILTER
0·25 mm. Al. EXTERNAL FILTER
0·10 mm. Al. EXTERNAL FILTER
0·05 mm. Al. EXTERNAL FILTER
SURFACE DOSE RATE IN RÖNTGENS PER MINUTE
TUBE-CURRENT IN MILLIAMPERES

Fig. 4. Dependence of tube output on tube-current at various filtrations for one K.V.P. setting — including both corrected and uncorrected chamber readings.

the nylon Victoreen for the basic measurements lies in their suitability for depth dose measurements, though once this information has been ascertained, the use of calibrated nylon Victoreens to measure (i) outputs and (ii) H.V.L.'s in Al., which could be related to H.V.D.'s in »tissue» from the present data, may be very valuable — provided the generator produces the same unidirectional pulsating tension, if accuracy is to be retained.

(b) *Dose Rate Dependence*

With the chamber voltage and electrode spacing used, readings of dose rates in excess of 1,000—1,200 r/min. are liable to loss on account of ionic recombination. The magnitude of this effect became clear as soon as it was attempted to measure high dose rates by timing deflections of the integrating ranges of the Dosemeter, and was later shown to be important at dose rates in excess of ~ 2,000 r/min. — a condition very frequently met with in the present work.

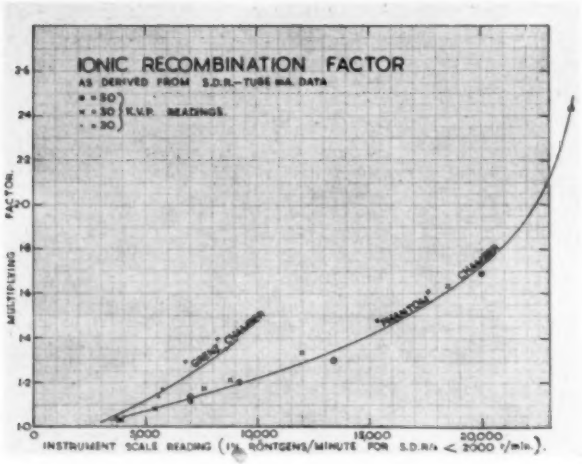


Fig. 5. Calibration of Siemens Chambers against radiation dose rate.

The correction factors to be applied to make allowances for this loss can be derived by plotting output readings (corrected for quality only) against the corresponding tube currents for a series of aluminium filtrations at a chosen K. V. P., as shown in Fig. 4 (full curves). This example relates to 50 K.V.P. measurements, further similar ones made at 20 and 30 K.V.P. providing additional and confirmatory data (as used in Fig. 5). Confining attention to the 3.22, 1.06 and 0.56 mm. Al. filtration curves only of Fig. 4 it is seen that the output-tube current relationship departs very slightly from linearity, but that it is independent of the filtration. This departure from linearity is found to increase as the K.V.P. decreases (See Fig. 8 in PART II), and will be further considered in PART II (§ 9 (c)); but turning to all the curves of Fig. 4, the filtration independence is found at all K.V.P.'s and is seen to apply to all outputs of less than ~ 3,000 r/min. Accordingly any change in the output-tube current curve-shape thus established is clearly due to ionic recombination losses, and hence provides a means of ascertaining the magnitude of these losses in each instance. The full curves in Fig. 4 indicate the instrument readings, whereas the dotted lines illustrate the estimated full outputs so derived (by calculation from the higher filter curves) in the case of outputs exceeding 3,000 r/min. Thence, by plotting the ratio of the instrument reading to the estimated full output against the instrument reading, over a range of outputs as shown in Fig. 5, multiplying factors applicable to any measured dose rate can be read off for either chamber.

The assumption that the filtration independence of the output-tube current curve-forms, established in the higher filtration cases, applies equally to the lower filtration ones also, finds confirmation in the fact that the applications of these factors immediately placed all data derived in the higher dose rate ranges into logical sequence. For example, the relatively fine differences in Al. H.V.L.'s for small filtrations in the 20—50 K.V.P. ranges when measured at tube currents of up to 50 mA (See PART II, Fig. 22), formed a useful test.

As a further confirmation of the correctness of these ionic recombination factors, F. BUSH[1] has attempted to derive recombination losses by a theoretical approach. Calculations showed that the Grenz ray chamber experimental correction curve (Fig. 5) was of the correct order, provided the electrode spacing was 5.5 mms. instead of the nominal 5 mms., a fact which was immediately verified. The multiplying factor may be shown to be dependent on the fourth power of the electrode spacing (which renders the effect extremely sensitive to this factor), and to the square of the applied voltage. Unlike the Grenz ray chamber, the phantom chamber was not amenable to theoretical treatment on account of the latter's cup-like shape, with a consequent field distortion.

Knowledge of these dose rate correction factors is essential in the measurement of penetration at high dose rates, for relative percentage readings are no longer valid, the effect of the dose rate correction factor decreasing as the actual dose rate decreases with depth.

### 7. The Measurement of Surface Dose Rates and Depth Dosage

Before giving results of the tube output measurements, a discussion of the material used as a »tissue-like» medium is necessary. At the harder qualities, this material provided the necessary backscatter for surface dose rate measurements, and at all qualities it formed the absorbing medium for depth dose measurements.

Initially, a series of »tissue-like» wax slabs of known thickness, composed of paraffin wax mixed with Mg 0 were used for all depth dose measurements. These were provided by the Siemens Company as an accessory to their Grenz ray measuring equipment, and are of the type used by CHAOUL (1944) in his measurements. However, a new »tissue-like» wax has recently been developed by D.E.A. JONES in collaboration with I.C.I. Ltd. (JONES and RAINE, 1949), the composition of which leads to an effective atomic number of 7.47 and an electron density of $3.36 \times 10^{23}$ per cc., both figures agreeing closely with the corresponding data for water. The mixture contains paraffin wax (60.8 %), polyethylene

[1] Private communication.

(30.4 %), magnesium oxide (6.4 %) and titanium dioxide (2.4 %), and not only are its absorption and scattering properties closely parallel to those of water, but the material can be cast into slabs of chosen thickness, these slabs being machined to the relevant accuracy for lower radiation qualities.

Wax slabs of 10.0, 5.00, 2.00, 1.00, 0.43, 0.25 and 0.20 mms. thickness were prepared, the latter three being only 2 cms. in diameter in order to ensure uniformity in thickness. (See Fig. 1, C in § 5.) The phantom chamber scattering material also consisted of the same »tissue-like» wax.

Following a suggestion made by JONES, the comparison of the properties of the new wax with those of water was made by means of a series of radiographs. At each of four radiation qualities, an appropriate thickness of wax (*i. e.* approximately double the H.V.D.) was floated in water in a thin-walled Perspex container, the sample being just submerged by means of a wire cross, in order to ensure the presence of the same total thickness of wax plus a little water in the centre region, and of water only in the surrounding area. By this means, the wax block should be invisible in a transmission radiograph if the wax behaves exactly like water as regards Roentgen ray absorption and scattering. The wax was found to be invisible at all penetrations down to 2.3 mms. H.V.D. (*i. e.* 20 K.V.P., 0.25 mm. Al. filter), at which quality the wax block shape was just perceptible under close observation. At an H.V.D. of 0.63 mm. (*i. e.* 10 K.V.P. and 0.10 mm. Al. filter), the wax shape could be seen, but the small difference in radiographic intensity was not considered to be significant.

Accordingly, this new wax was adopted, and all the measurements entailing scatter contributions reported below relate to its use, the initial work carried out with the Siemens wax being repeated. However, it must be added that the difference in percentage depth dose measurements made with the two waxes was insignificant at the harder qualities concerned, and amounted to only a few per cent in the softer range.

It will be realised that the use of the above »tissue-like» wax is based on the assumption that water is a close enough substitute for tissue as regards Roentgen ray absorption and scatter. This is, it is realised, only a first approximation at such low voltage radiation, and in view of this, it is planned to carry out in the future a complete new series of absorption measurements in wet tissue.

In Denmark, EBBEHÖJ (1937) made his depth dose measurements in specially prepared waxed paper, and the small measure of disagreement between his later work (1948) and the present data (see PART II, § 10 (*i*)) is no doubt partly due to a difference in the absorbing media employed.

## 8. K.V.P. Calibrations

From 50 K.V.P. down to 15 K.V.P. a sphere gap was used for the calibration, whereas from 0 up to 15 K.V.P. a condenser and electrostatic voltmeter system was employed. The setting indicated on a pre-reading voltmeter in the tube control panel corresponding to a particular K.V.P. is, however, dependent on the tube current, so that a complete range of K.V.P. — pre-reading settings was carried out for three tube currents, namely 50.0, 25.0 and 2.5 mA. Owing to the magnetic field effects of a large choke in the provisional control panel, the calibration curve at the smallest current was found to intersect the other two at the higher voltages used, as shown in Fig. 6.

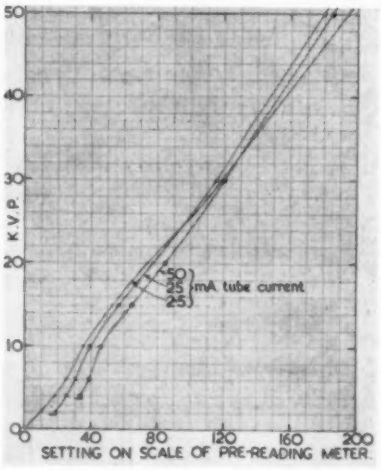


Fig. 6. Calibration of the pre-reading voltmeter against K.V.P. at three tube current settings.

The minimum K.V.P. attainable at each tube current was found to be limited by the maximum permissible filament current, the necessary level of which is determined by the tube space-charge characteristics. Thus at the currents of 50 mA and 25 mA, the necessary filament current reached its maximum at 4 K.V.P. and 2 K.V.P. respectively.

Although all tube calibration work was based on the above three tube currents, it was later found to be desirable to use settings at 5 mA and 10 mA as well in order to obtain a wider choice of treatment times for any chosen penetration. In view of the difficulty of interpolation in Fig. 6, preliminary choices of appropriate pre-reading settings for the desired K.V.P.'s at these new tube currents were confirmed or modified by subsequent roentgen ray penetration tests, for it had been found (See PART II, § 10 (e)) that the radiation quality was independent of the tube current for the three fully calibrated values of the latter.

* * *

The experimental results and their application will be given in PART II, together with the references.

# PART II

# THE EXPERIMENTAL RESULTS AND THEIR APPLICATION

## 9. Surface Dose Rate Data

(a) *Maximum surface dose rates* (*S.D.R.'s*)

Adopting a basic F.S.D. of 10 cms, and a circular field of 5 cms. diameter, measurements made with the Unit[1] operated at its maximum tube current rating of 50 mA gave the following surface dose rates for the range of K.V.P. and filtration shown (Table I). The nominal inherent filtration is 1.0 mm. beryllium.

**Table I**

| K.V.P. | External filtration in mms. aluminium | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.0 | 0.05 | 0.10 | 0.25 | 0.56 | 1.06 | 3.22 |
| | S.D.R.'s in roentgens per minute (for a 5.0 cms. diam. field at 10 cms. F.S.D.) | | | | | | |
| 50 | 59,000 | 34,000 | 22,000 | 8,250 | 2,860 | 1,500 | 455 |
| 30 | 30,300 | 16,500 | 10,900 | 3,960 | 1,290 | 600 | 100 |
| 20 | 11,600 | 6,400 | 3,900 | 1,530 | 422 | 137 | — |
| 10 | 1,380 | 340 | 120 | — | — | — | — |
| 8 | 770 | — | — | — | — | — | — |
| 6 | 353 | — | — | — | — | — | — |
| 5 | 153 | — | — | — | — | — | — |
| 4 | 25.8 | — | — | — | — | — | — |
| | Backscatter negligible | | | | Including backscatter | | |

Reducing the K.V.P. further entails a reduction in the tube current, but at 3 K.V.P., 25 mA tube current, and zero external filtration the output is ~ 4 r/min. at 10 cms. F.S.D.; whereas at 2 K.V.P., the output can just be detected at 3.5 cms. F.S.D., a rough estimate of the rate at 25 mA and zero external filtration being ~ 0.3 r/min.

The data in Table I have been plotted in one form in Fig. 7 and thence analysed as below. Plots of output against filtration at different K.V.P.'s can also be derived from the Table and were necessary for the completion of Fig. 15 (§ 10 (b)).

[1] The Unit consists of a Machlett AEG-50-T Tube energised by equipment, providing unidirectional pulsating tension, supplied by Messrs. Watson & Sons (Electro-Medical) Ltd.

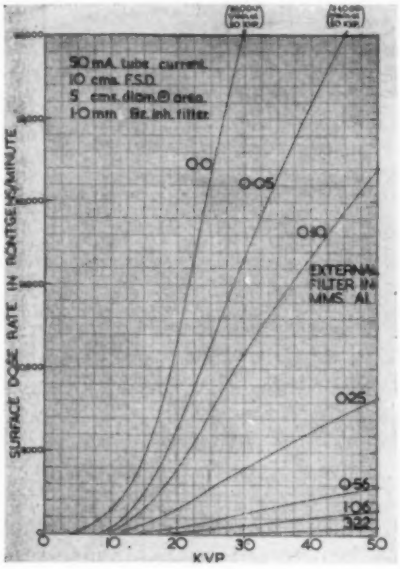


Fig. 7. The dependence of tube output on K.V.P. and filtration at one tube-current.

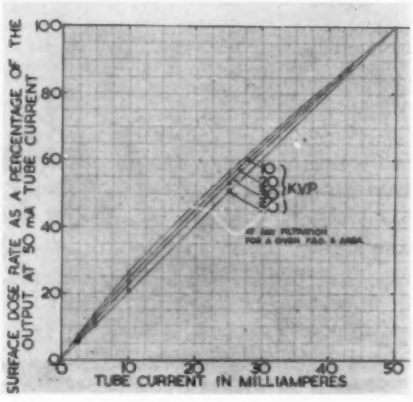


Fig. 8. The dependence of tube output on tube-current and K.V.P. at any filtration.

(b) *The relation of output*[1] *to K.V.P. at various filtrations*

This relationship is generally considered in the form: output $= kV^n$, where k is a constant. However, the value of the exponent n is found to vary considerably with the peak voltage V, and to a lesser extent on the filtration, over the ranges concerned. Thus, the value of n decreases with a decrease in filtration, but rises with a fall in K.V.P. Table I gives the dose rates measured with backscatter; reducing these to air dose rates[2] the value of n can be obtained for any chosen setting by taking the slopes of »log output» against »log V» curves at the appropriate point. The results are given in Table II, from which it is seen that the equation »output $= kV^n$» has little meaning in so far as n is clearly not a constant, but is a function of both V and the filtration.

It will be realised that the above data refer to air dose rates, and not to intensities, and that the minimum filtration used still includes 1 mm. Be + 8 cms. air. This contrasts with the published data relating

[1] The term »output» is used to signify dose rates, not intensities, throughout.

[2] This can be done with the aid of Fig. 10, § 9 (d), the correction factor for zero area (*i. e.* air D. R.) being approximately twice that plotted for the 1.5 cms. diameter circle area.

**Table II**[1]

| K.V.P. dependence for zero external filtration | | Filtration dependence at 40 K.V.P. | |
|---|---|---|---|
| K.V.P. | n | mms. Al. ext. filter | n |
| 40 | 1.30 | 0.0 | 1.30 |
| 30 | 1.73 | 0.05 | 1.33 |
| 20 | 2.40 | 0.10 | 1.36 |
| 10 | 3.30 | 0.25 | 1.43 |
| 8 | 3.60 | 0.56 | 1.54 |
| | | 1.06 | 1.67 |

to the variation of the total intensity of the continuous Roentgen ray spectrum with applied (constant) voltage. For zero filtration, this has been shown to be proportional to $V^2$ down to 8.5 K.V., and to higher powers of V at lower voltages (STEPHENSON and MASON, 1949). The discrepancy between the dose rate variation and the intensity variation with K.V. (constant potential) at low filtrations has been discussed by ROBERTS (1934) who showed that the increased absorption of the long wavelength components of the radiation in air tends to mask the actual variation in intensity when the inonization method is used for measurement.

(c) *The dependence of output on tube current*

Under constant potential conditions, the output is generally proportional to the tube current employed, other factors remaining unchanged. In the present case, however, the use of a pulsating tension leads to a departure from this linear relationship, the deviation increasing as either the K.V.P. or the tube current are decreased.

Fig. 8 shows the relationship between the S.D.R., expressed as a percentage of the output at 50 mA, and the tube current at four K.V.P. settings. (It will be recalled from Fig. 4 (in PART I) which showed corresponding graphs for the 50 K.V.P. case only at six values of the filtration, that these curves are not dependent on the filtration.) The deviation from linearity of these output-tube current curves can best be shown by plotting this deviation as a multiplying factor against K.V.P. for different tube currents as shown in Fig. 9.

The significance of this deviation is to be found by a consideration of the consequences of using a pulsating tension which includes space-charge effects, the rate of growth of the current against time and its phase relationship to the applied voltage. Further, the distribution of energy among the component Roentgen ray wavelengths will vary con-

[1] See § 9 (h) below for comparison with theory.

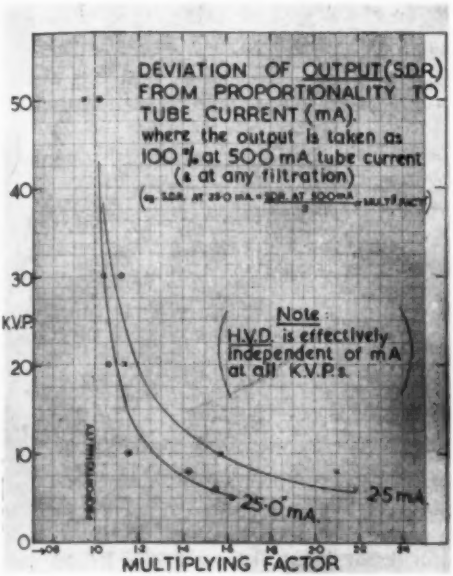
DEVIATION OF OUTPUT (S.D.R.) FROM PROPORTIONALITY TO TUBE CURRENT (mA).
where the output is taken as 100 % at 500 mA tube current (& at any filtration)
Note: H.V.D. is effectively independent of mA at all K.V.P.s.
25·0 mA.
2·5 mA.
K.V.P.
MULTIPLYING FACTOR

Fig. 9.

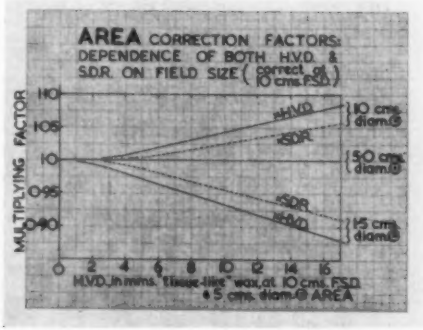
AREA CORRECTION FACTORS: DEPENDENCE OF BOTH H.V.D. & S.D.R. ON FIELD SIZE (correct. at 10 cms. F.S.D.)
MULTIPLYING FACTOR
10 cms. diam.
5·0 cms. diam.
1·5 cms. diam.
H.V.D. in mms. Tissue-like wax at 10 cms. F.S.D.
• 5 cms. diam. = AREA

Fig. 10. The dependence of both radiation penetration (H.V.D.) and surface dose rate (S.D.R.) on field area.

tinuously, the harder components being present for part only of each cycle. These combined effects have been found to result in a larger output in relation to the tube current indicated, for small values of the tube current than at higher values, this deviation being marked at low K.V.P.'s and decreasing to nothing as the K.V.P. approaches 50. On the other hand BIRKMAN's (1948) output data (also measured under pulsating tension) includes one pair of results in which the tube current is the only variable, and he finds that a reduction in the tube current by a factor of five leads to a sixfold fall in output. Thus, this deviation from proportionality is in the reverse direction to that found above.

From the penetration standpoint, however, it is found that the variation in tube current does not influence the mean quality as measured in terms of H.V.D. to any appreciable extent, a result confirmed in BIRKMAN's measurements in terms of H.V.L. in Al.

In other words, although the output is not just proportional to the tube current at any K.V.P., the radiation quality was not found to be appreciably influenced by this variable. It is planned to investigate this whole problem further, and in this connection a rapid response inonization chamber and amplifier[1] is under construction in order to project

[1] To a design due to S. J. Wyard.

the variation of dose rate during each cycle on to an oscillograph screen under the complete range of conditions. For practical purposes, a Table (IX) of outputs relating to tube currents of 50, 25, 10, 5 and 2.5 mA over the complete range of qualities has been prepared from measured dose rates, and is given in part in § 13 (b).

(d) *The dependence of S.D.R. on field area*

Choosing an F.S.D. of 10 cms., S.D.R.'s were measured over the complete range of penetrations concerned for field areas given by 1.5, 5.0 and 10.0 cms. diameter circles, S.D.R.'s for other field areas being derived by interpolation.

With the 5.0 cms. diameter circular field as basis, multiplying factors relating to the corresponding S.D.R.'s for the other two areas plotted against the radiation penetration expressed in terms of H.V.D. in »tissue« are given in Fig. 10 (the dotted curves) and are also tabulated in Table IX, § 13 (b). It will be seen that the scatter contribution decreases almost linearly with penetration, becoming negligible at 3—4 mms. H.V.D.

Thus, given data for S.D.R.'s applicable to the basic 5.0 cms. diameter applicator, S.D.R.'s for other areas can be obtained from these graphs. Strictly, these area correction factors apply only at 10 cms. F.S.D., but their use at other F.S.D.'s entails a second order error only.

Comparison with the results obtained by other workers is limited to data contributed by BRAESTRUP to a recent book (1944), none other having come to the author's notice.

Braestrup's data, expressed in terms of H.V.L. in Al., and measured at 15 cms. F.S.D., can be translated to the form of Fig. 10, and is found to agree very closely, though the lowest quality used corresponds to 11 mms. H.V.D. only.

(e) *The variation in S.D.R. over the field area*

Using a diaphragm on the Unit to limit the irradiated field diameter to a value equal to one half the F.S.D., S.D.R. readings were taken at a series of points over the entire field area, the chamber being inclined to face the target at all points. Figure 11 shows the distribution in the S.D.R. found at 50 cms. F.S.D. at a radiation penetration of 4.3 mms. H.V.D., the centre point being taken as 100 % as it forms the basis of all the output data. The percentage pattern shown will apply (to a first approximation) at any F.S.D. for a field diameter equal to one half the F.S.D. concerned.

Taking an anode-cathode section, comparison to a publication by LEWIS and MUTSCHELLER (1949) can be made, and a close agreement is found, though the rate of cut-off on the cathode side is slightly greater in the present instance. This distribution closely resembles that obtained

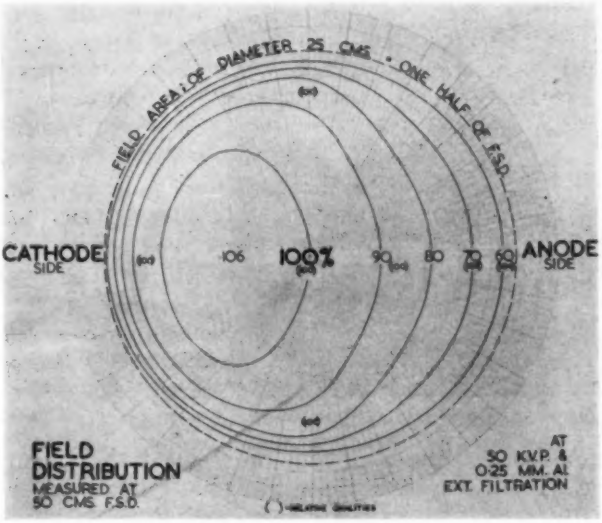


Fig. 11. The distribution of radiation intensity over a field of diameter equal to half the F.S.D.

in the case of diagnostic tubes, as measured by L. A. W. KEMP,[1] and can be attributed to the steep inclination of the target (22° to the vertical).

Possible ways to render the S.D.R. more even over the field area include:

I. The use of uneven filters; this is not recommended, for a different filter would be needed for every quality, and the transmitted quality would then vary over the field area.

II. The inclination of the applicator to centre on the point of highest S.D.R.; this is not practicable owing to the rapid fall-off on the cathode side — even when the limiting diaphragm is removed.

III. Modification in the target design[2]; a less steeply inclined target would improve the distribution, though a slightly lower output would be available if the penumbrae are to remain limited.

IV. The applicator system can be designed to utilise part only of the field area, the irradiated portion being chosen in accordance with the isodose curves of Figure 11.

It will be noted that for the radiation quality used in the above distribution measurements, there is only a 4 % hardening on the anode side, the penetration remaining nearly uniform over the field area.

[1] Private communication.

[2] This approach has recently been adopted by the Mathlett Laboratories, Inc., who have incorporated a 45° target in the OEG — 60 Tube (ROGERS, 1949—50).

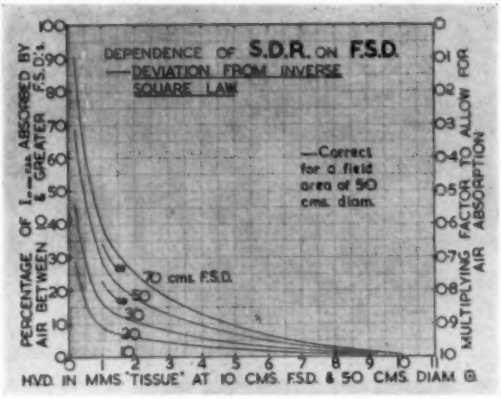
DEPENDENCE OF S.D.R. ON F.S.D.
—DEVIATION FROM INVERSE SQUARE LAW
—Correct for a field area of 50 cms. diam.
70 cms. F.S.D.
50
30
20
10
PERCENTAGE OF I.—ray ABSORBED BY AIR BETWEEN F.S.D.'s & GREATER
MULTIPLYING FACTOR TO ALLOW FOR AIR ABSORPTION
H.V.D. IN MMS. "TISSUE" AT 10 CMS. F.S.D. & 50 CMS. DIAM. ⊕

Fig. 12. The dependence of surface dose rate on focal—skin-distance.

For comparison purposes, it will be recalled that using an F.S.D. of 2 cms., the Phillips system yields practically hemi-spherical isodoses, whereas isodoses relating to the Chaoul technique (at 5 cms. F.S.D.) are included on pages 79—85 of CHAOUL's book (1944). It is planned to determine the depth isodoses in the present system by a photographic approach but difficulties relating to the absorption »edges» of both silver and bromine in the range of K.V.'s concerned remain to be considered.

(f) *The dependence of S.D.R. on F.S.D.*

Using the 5 cms. diameter circular field, S.D.R.'s were measured over the complete range of qualities concerned for F.S.D.'s of 10, 20, 30, 50 and 70 cms., S.D.R.'s for intermediate F.S.D.'s being derived by interpolation. F.S.D.'s less than 10 cms. have not been used, except in the detection of 2 K.V.P. radiation.

At penetrations in excess of ~ 12 mms. H.V.D., the dose rate (in air) is found (as generally assumed) to follow the inverse square law over such an F.S.D. range, but as the radiation becomes softer, the absorption losses in the intervening air become increasingly significant, and must be taken into account. Thus, in addition to the inverse square law factor, a multiplying factor which represents the deviation from this law has to be applied, its value depending on the F.S.D. and the radiation quality. These measured correction factors, plotted against the penetration expressed in terms of H.V.D. in »tissue», are given in Fig. 12, and are also tabulated in Table IX, § 13 (b). Although these F.S.D. correction factors relate only to the 5 cms. diameter applicator, their use for other field areas entails a second order error only.

In Table IX, the air loss factors have not been combined with the

inverse square fall correction factors (applicable to 20, 30, 50 and 70 cms. F.S.D.) in order to facilitate interpolation of the former factors for use with applicators of intermediate F.S.D.'s. Thus, to each applicator whose F.S.D. is other than 10 cms., an inverse square law factor will always apply, and only the air loss factors need then be determined each time in relation to the H.V.D. to be used.

It will be seen that the air loss factors increase very rapidly for H.V.D.'s less than 0.6 mm. and are roughly in proportion to F.S.D. for H.V.D.'s between 0.6 and 6 mms.

Accurate data relating to the absorption of roentgen rays in air from a beryllium window tube operated down to 7.5 K.V. (constant potential) has been published by DAY and TAYLOR (1949). Their results, when translated to the form given here, are found to agree closely with those derived in the present work. Further, the corresponding data derived from BRAESTRUP's tables contributed to the book referred to above (§ 9 (d)) are also in agreement with the present measurements.

The advantages of increasing the F.S.D. to values greater than the 10 cms. standard are: (i) increased field area, the diameter of which is a definite fraction of the F.S.D. (up to one half); however, the relatively large focal spot size (5 × 5 mms.) leads to an appreciable penumbra, so that a protective surround leaving an aperture smaller than the inside of the penumbra is desirable. (ii) Smaller percentage variations in dosage in the treatment of curved surface, or a smaller fall-off in dosage towards the sides of the field in relation to the centre if only the central region of a larger area is used. The normally applicable advantage of increased penetration (H.V.D.) at greater F.S.D.'s due to a lesser inverse square law reduction in dose rate in the tissue (*e.g.* at 200 K.V.P.) is *not* relevant, for an increase in the H.V.D. can be more easily achieved by increasing either the K.V.P. or the filtration a little, thereby retaining the convenience and high dose rates applicable at low F.S.D.'s and avoiding the introduction of air loss factors.

(g) *Further comparisons of the present output data with other published experimental work*

As previously mentioned, BRAESTRUP (1945—6), BIRKMAN (1948) and EBBEHÖJ (1948) have provided some tentative data relating to beryllium window tube outputs. Though measured under different conditions, some general comparisons may be of interest.

BRAESTRUP's measurements were all made at 2 mA tube current and 10 cms. F.S.D., and were limited to a range of filtration all used at 50 K.V. only. Operated at constant potential, the outputs are accordingly higher than those of Table I (§ 9 (a)), but the ratio of the outputs

(expressed in r/min/mA[1]) remains approximately constant at 8 : 5 over the entire range of filtration, with the exception of the zero external filter reading which falls in the ratio 8 : 6 (see below). The constancy of this ratio lends support to the correctness of the respective instrumental calibrations.

BIRKMAN's data, though derived from an apparatus operated under fluctuating potential (half-wave rectified) gives lower outputs than those of Table I. Limited to 50 K.V.P. and measured at 15 cms. F.S.D. under filtration conditions down to 0.5 mm. Al., the ratio of outputs is again approximately constant over the entire range concerned, standing at 5 : 7.

EBBEHÖJ's measurements, covering a wider range of K.V.P.'s, with a small range of filtration at each K.V.P. setting, were also made at 10 cms. F.S.D. and at 10 mA. The outputs given are even lower than those of BIRKMAN, falling in the ratio 3 : 5 with those of Table I as regards all filters given at 20 and 30 K.V.P. At 50 K.V.P. the ratio is nearer 9 : 10 — a change in the constancy of the ratio not supported by the American work, whereas the low voltage data (below 15 K.V.P.) cannot be compared at present as the readings were taken at 5 cms. F.S.D. and the air loss factors cannot be accurately extrapolated.

The difference between the outputs of these several Tubes may be accounted for by different energising circuits, or by a difference in the overriding calibration factor translating instrumental readings into roentgens per minute, such a difference covering the entire range in each case. In the present work, the Standard air-chamber of the National Physical Laboratory provided the basic data.

A further recent calibration is of interest. The same measuring apparatus was used to derive the outputs of a second beryllium window Tube installed in another London hospital, this Unit being designed to operate over the range 8—19.5 K.V.P., with a circuit similar to that used for the Unit used in the present work. Though small differences between the respective outputs occurred at settings in the upper half of the K.V.P. range, these differences were random, and the output data for the lower settings agreed very closely at the tube currents used (2.5—15 mA). This agreement may be fortuitous in so far as the thickness of the beryllium forming the window is not guaranteed to a high accuracy, and the output at zero filtration, particularly at low K.V.P.'s, is extremely sensitive to this thickness. The influence which small changes in this factor can exert on radiation quality will be discussed below (§ 12 (c)). This consideration may be relevant to the observed change in the ratio, at zero external filtration, of BRAESTRUP's data to that given in Table I (§ 9 (a)).

[1] This expression holds for any tube current at 50 K.V.P.

(h) *Comparison of experimental output data with theory*

Although not yet complete, an attempt to establish the corresponding output data on a theoretical basis has been made by F. BUSH.[1] The problem is complicated by the use of a pulsating tension instead of a constant potential.

Preliminary results lend support to the above experimental data, but suggest that the beryllium window of the Tube used has a thickness of ~ 0.2 mm. in excess of the nominal 1.0 mm. Thus, the calculated data relating to a corresponding total filtration of 1.0 mm. Be + 0.025 mm. Al.[2] (+ 8 cms. air) yield output data closely corresponding to the measured results for zero filtration — an interpretation also supported by the data relating to absorption in aluminium. Expressed as a percentage of the output at 50 K.V.P., Table III gives the available data based on a tube current of 50 mA.

**Table III**

| K.V.P. | Experimental data for zero ext. filter (from Table I) | Calculated data for 0.025 mm. Al. ext. filter (Bush) |
|---|---|---|
| 50 | 100 % | 100 % |
| 30 | 51.5 % | 45.0 % |
| 20 | 19.7 % | 20.6 % |
| 10 | 2.4 % | 2.9 % |
| 5 | 0.26 % | 0.27 % |

The relation of output to K.V.P. at various filtrations in the calculated data is found to confirm the main trends found experimentally. Thus, the exponent n in the (previously discussed) relation: output $= kV^n$ is shown to decrease with a decrease in filtration, and to rise with a fall in K.V.P., the actual values being similar to those determined experimentally, though the calculations have not yet been extended beyond a 0.2 mm. thickness of Al. filtration. Thus, reducing the K.V.P. from 40 to 8 with zero external filtration, the value of n rises from 1.35 to 3.9 — figures to be compared with 1.30 and 3.6 in Table II (§ 9 (b)).

## 10. Depth Dosage in »Tissue»

(a) *Introduction*

The medium used for the following depth dosage measurements was the »tissue-like» wax, the properties of which have been discussed in PART I, (§ 7).

[1] Private communication.

[2] 0.025 mm. Al. is approximately equivalent to 0.2 mm Be in this connection.

Fig. 13 a.

Fig. 13 b.

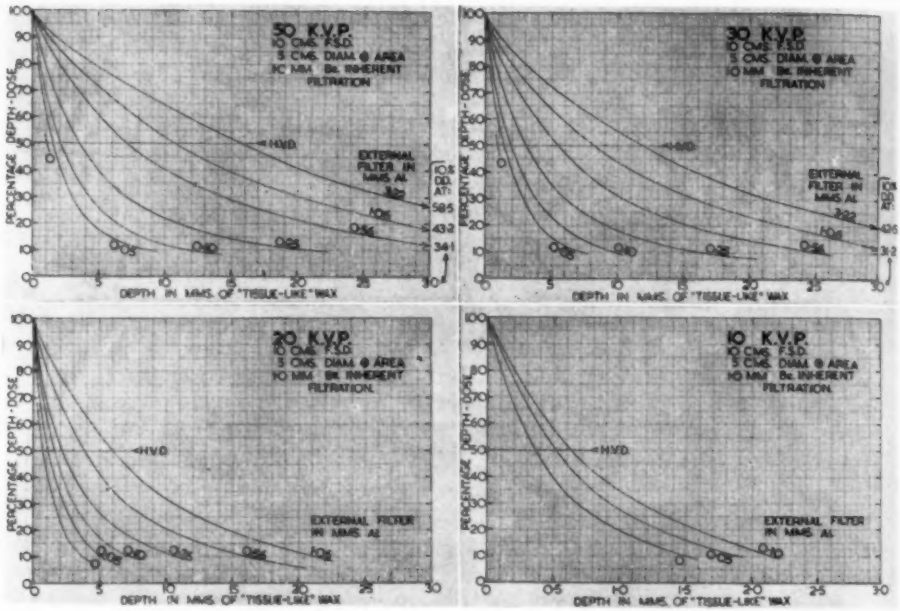


Fig. 13 c.

Fig. 13 d.

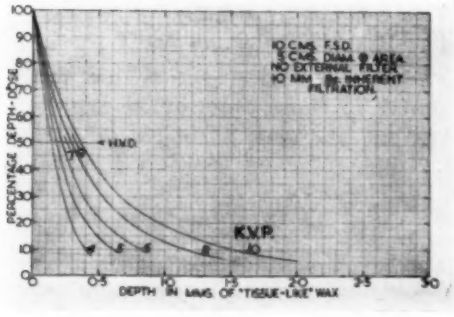


Fig. 14.

Fig. 13. Percentage depth-dose curves at 50, 30, 20 and 10 K.V.P. for a range of filtrations in each case.

Fig. 14. Percentage depth-dose curves for zero filtration at a range of low K.V.P.'s.

Depth dose curves, expressed in terms of the percentage of the surface dose rate, were measured over the entire range of qualities available, and over a wide range of surface dose rates in each instance. Choosing, as in the S.D.R. measurements, the basic 5.0 cms. diameter circular

field with a 10 cms. F.S.D., depth dose curves were measured at 50, 30, 20 and 10 K.V.P. for each of a series of filtrations[1] and also at 8, 6, 5 and 4 K.V.P. for zero external filtration only. All these curves, plotted down to the 90 % absorbed level, are given in Figs. 13—14. It will be noted that at 4 K.V.P., the minimum wax thickness of 0.20 mm. prepared led to a 35 % percentage depth dose as first reading — just about adequate to determine the H.V.D. of the softest radiation used.

These depth dose curves represent the central axis of the beam only but it was shown in Figure 11 (§ 9 (e)), that the quality varies only slightly over the field area used.

(b) *Half-value-depth (H.V.D.) in »tissue»*

As a first simplifying step, the measurement of the depth at which the dose rate falls to 50 % of the S.D.R. forms a useful measure of the radiation »penetration» embracing the K.V.P. and filtration, and it will also take into account any variation due to F.S.D. and field area changes.

Values of H.V.D. covering the entire quality range (for a 5.0 cms. diameter field at 10 cms. F.S.D.) can be read from the curves in Figs. 13—14 and are given in Table IV.

**Table IV**

| K.V.P. | External filtration in mms. aluminium | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.0 | 0.05 | 0.10 | 0.25 | 0.56 | 1.06 | 3.22 |
| | H.V.D.'s in mms. of »tissue-like» wax (for a 5.0 cms. diam. field at 10 cms. F. S. D.) | | | | | | |
| 50 | 1.05 | 1.55 | 2.10 | 3.50 | 7.10 | 10.8 | 15.8 |
| 30 | 0.90 | 1.40 | 1.90 | 3.00 | 5.50 | 8.20 | 12.0 |
| 20 | 0.70 | 1.10 | 1.55 | 2.15 | 3.85 | 6.00 | — |
| 10 | 0.36 | 0.52 | 0.63 | — | — | — | — |
| 8 | 0.29 | — | — | — | — | — | — |
| 6 | 0.22 | — | — | — | — | — | — |
| 5 | 0.18 | — | — | — | — | — | — |
| 4 | 0.14 | — | — | — | — | — | — |

These data can now be plotted in two ways. Firstly, the H.V.D.'s can be plotted against K.V.P. for each filtration as shown in Fig. 15, thereby providing the requisite K.V.P. settings for a chosen H.V.D. within the range covered by each filter thickness. Alternatively, plotting H.V.D.'s against filtration for each K.V.P., as shown in Fig. 16, provides the necessary data to draw the more useful curves of Fig. 15 for any chosen filtration. This has been done to derive the filter curves of

[1] The maximum thickness of which was determined by that which gave an S.D.R. in excess of 100 r/min. at 50 mA.

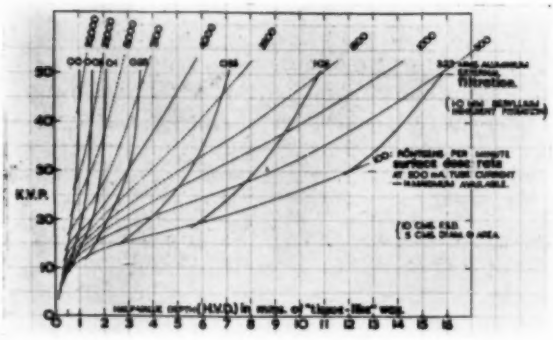

Fig. 15.

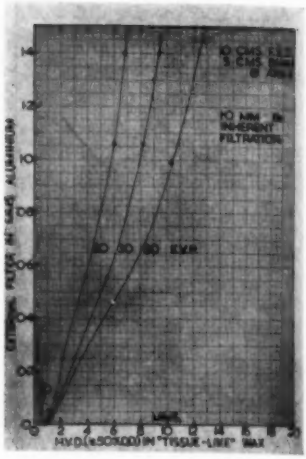

Fig. 16.

Fig. 15. The dependence of half-value-depth in »tissue» (H.V.D.) on K.V.P. and filtration, and of surface dose rate on K.V.P. and H.V.D. (at one tube current setting).

Fig. 16. The dependence of half-value-depth in »tissue» on K.V.P. and filtration.

Fig. 20 (§ 11 (c)). It will be appreciated that the K.V.P.—H.V.D. curves are the more practical, for unlike the filter thickness, the K.V.P. can always be continuously varied to provide any chosen H.V.D. deemed appropriate on clinical grounds. Next, with the aid of Fig. 7 (§ 9 (a)), S.D.R. data can be added to Fig. 15 (the dotted curves) making it possible to estimate the S.D.R. for any given filter and K.V.P. pair corresponding to a chosen H.V.D. The use of the resulting chart will be further discussed in § 11 (e) and § 13 below.

In passing, it will be noted that the curves in Fig. 16 show a slight bend at an external filter thickness of $\sim 0.25$ mm. Al., a deviation which is also present in the corresponding curves for aluminium absorption (see Fig. 22 § 12 (a)) and which becomes more pronounced when the »fall-off» ratio is considered (see Fig. 19 § 11 (b)).

(c) *Dependence of H.V.D. on field area*

Depth dose curves were measured at 10 cms. F.S.D. for three field areas, 10.0, 5.0 and 1.5 cms. diameter circles, at each of a number of radiation qualities covering the entire range available. Based on the 5.0 cms. diameter field, correction factors for any given quality can be derived rom the graphs (the full curves) included in Fig. 10, § 9 (d), intermediate

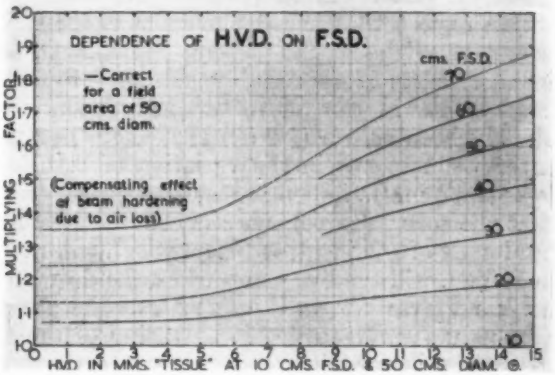


Fig. 17. The dependence of half-value-depth in »tissue» on focal—skin-distance.

area factors being derived by interpolation. The data relating to these curves are included in Table IX, § 13 (b). Although these multiplying factors apply strictly only at 10 cms. F.S.D., their use at other F.S.D.'s entails a second order error only.

As in the discussion relating to the variation of S.D.R. with field area, the only published work with which comparison can be made is that of BRAESTRUP (1944), whose Tables refer to penetration down to 11 mms. H.V.D. only. In the range above this, the 10 cms. diameter circle area correction factor graph agrees well with his work, though he records a slightly greater fall in depth dosage with small areas (*e. g.* the 1.5 cms. diameter field graph).

(d) *Dependence of H.V.D. on F.S.D.*[1]

Depth dose curves were measured at 10, 20, 30, 50 and 70 cms. F.S.D. for a 5.0 cms. diameter circular area, at each of a number of radiation qualities covering the entire range available. Based on the H.V.D.'s applicable at 10 cms. F.S.D., correction factors for any given quality can be derived from the curves given in Fig. 17, intermediate F.S.D. factors being derived by interpolation. The data relating to these curves are included in Table IX, § 13 (b). Strictly, these multiplying factors apply only to a 5.0 cms. diameter field, but their use for other field areas entails a second order error only.

The shape of the curves in Fig. 17 merits discussion. The numerical value of a particular H.V.D. depends on two independent factors (i) the absorption of the radiation, and (ii) the inverse square law. It is evident that for a particular F.S.D. the influence of the latter factor on

[1] The merits of increasing the F.S.D. beyond 10 cms. are discussed in § 9 (f).

the total effect will decrease as the penetration decreases. Thus, one would expect that the dependence of the H.V.D. on a change in F.S.D. would also fall continuously as the H.V.D. itself decreases, unless the incident beam is appreciably hardened by the absorption of the softer components in the additional intervening air thickness. Now it has already been shown (§ 9 (f)) that there is a marked deviation from the inverse square law in the variation of S.D.R. with F.S.D. for H.V.D.'s less than 4 mms., indicating air absorption, and it is reasonable to assume that the softer components are differentially absorbed. Accordingly, this hardening of the incident beam, which will increase a little with decrease in H.V.D. will tend to compensate the decreased percentage effect of the inverse square law on the H.V.D. as the penetration is reduced. In the present measurements, this balancing of opposed tendencies was found to lead to approximately constant correction factors (for change in H.V.D. with F.S.D.) for H.V.D.'s less than 4 mms., the actual value increasing with F.S.D. as shown in Fig. 17.

Comparison with other (published) work is possible for the highest and lowest qualities only. For soft radiation, DAY (1949) finds no appreciable change in quality due to air absorption down to 7.5 K.V., but the minimum F.S.D. which could be used with the Standard air chamber was 119 cms. of air, so that the beam would be highly filtered in any case. Other papers relating to the clinical applications of Grenz rays refer to the hardening effects of increased F.S.D.'s in general terms.

At higher qualities, BRAESTRUP's (1944) tables referring to H.V.D.'s down to 11 mms. »tissue» give slightly smaller factors for the dependence of H.V.D. on F.S.D.

(e) *Dependence of H.V.D. on tube current*

Depth dose curves were measured at 2.5, 25 and 50 mA tube currents at a series of qualities covering the entire range available. The resulting H.V.D.'s derived were found to be approximately independent of the tube current used.

(f) *Further comparisons with other available data relating to »tissue» depth dosage*

EBBEHÖJ (1948) has published a series of depth dose curves measured in waxed paper for the radiation from a beryllium window tube operated over a range of K.V.P. under two or three filtration conditions. Comparison of the H.V.D.'s of these curves with those of Table III shows a measure of disagreement at 50 K.V.P. of the order of 1.5/1.0, though the ratio is reduced at lower K.V.P's. This difference is probably due to the different media used for the depth dose measurements, and possibly on account

of different applied voltage waveforms or different tube window thicknesses.

Comparison with BUSH's calculated data (see § 9 (h)) is at present limited to 10 K.V.P. data, for the contributions from scattered radiations have not yet been included. These are now under consideration. However, at these very low penetrations, the results appear to confirm the previous inference that the beryllium window has thickness of 1.2 mms. Thus, the calculated H.V.D.'s applicable for 0.0 and 0.025 mm. Al. external filtration (at 10 K.V.P.) are 0.195 and 0.30 mm. respectively, results to be compared with an experimental figure of 0.36 mm. for zero external filtration (Table IV, § 10 (b)).

LEA (1946) has also calculated energy absorption in tissue for Grenz radiation, and states that monochromatic radiation of 1.5 Å is reduced to half its intensity by passage through 695 $\mu$ thickness of water. This quality corresponds to an H.V.D. of 0.695 mm. at 8.25 K.V. highly filtered, which may be compared to the penetration of 0.63 mm. H.V.D. for 10 K.V.P. radiation with 0.10 mm. Al. filter (Table IV, § 10 (b)).

One further method of deriving H.V.D.'s for such soft radiation is described by ANDREWS and BRAESTRUP (1936) though no depth dose curves are given. This consists in the use of an inclined film immersed in water. By the use of a suitable gradient, the variation in blackening which occurs on exposure over the first few millimetres depth can be spread over a wide area of film surface.

### 11. 90 % Absorption Depth and the »Fall-Off« Ratio (F.O.R.)

(a) As stated in § 10 (a), the depth dose curves given in Figs. 13—14 were measured down to the 90 % absorbed level. Accordingly, covering the same range of K.V.P. and filtration, Table V includes the data relating to this depth in the same way as Table IV (§ 10 (b)) gives for the H.V.D.

**Table V**

| K.V.P. | External filtration in mms. aluminium | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.0 | 0.05 | 0.10 | 0.25 | 0.56 | 1.06 | 3.22 |
| | 90 % absorption depth in mms. of »tissue-like« wax (for a 5.0 cms. diam. field at 10 cms. F.S.D.) | | | | | | |
| 50 | — | 8.60 | 11.7 | 21.0 | 34.1 | 43.2 | 58.5 |
| 30 | — | 7.20 | 9.60 | 15.9 | 24.7 | 31.2 | 42.5 |
| 20 | 3.68 | 5.10 | 7.40 | 10.7 | 16.0 | 21.0 | — |
| 10 | 1.50 | 1.89 | 2.14 | — | — | — | — |
| 8 | 1.15 | — | — | — | — | — | — |
| 6 | 0.81 | — | — | — | — | — | — |
| 5 | 0.60 | — | — | — | — | — | — |
| 4 | 0.40 | — | — | — | — | — | — |

Plotting the 90 % absorption depths against filtration for each K.V.P. gives the graphs shown in Fig. 18, these curves corresponding to those of Figs. 16 for H.V.D. data.

(b) *»Fall-off» ratio data*

The next step consists in taking the ratio of the 90 % absorbed depth to the H.V.D. for each K.V.P. and filtration condition, this ratio being termed the »fall-off» ratio (F.O.R.), for it gives an indication of the rate at which the radiation falls in intensity will depth beyond the H.V.D. This rate of fall-off is found to be a variable of practical significance.[1]

Thus, dividing each figure in Table V by the corresponding figure in Table IV (§ 10 (b)), the resulting F.O.R.'s are as shown in Table VI.

**Table VI**

| K.V.P. | External filtration in mms. aluminium | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.0 | 0.05 | 0.10 | 0.25 | 0.56 | 1.06 | 3.22 |
| | Fall-off factors for »tissue-like» wax absorption | | | | | | |
| 50 | — | 5.55 | 5.60 | 6.00 | 4.80 | 4.00 | 3.70 |
| 30 | — | 5.15 | 5.05 | 5.30 | 4.50 | 3.80 | 3.55 |
| 20 | 5.25 | 4.90 | 4.80 | 5.00 | 4.15 | 3.50 | — |
| 10 | 4.15 | 3.65 | 3.40 | — | — | — | — |
| 8 | 3.95 | — | — | — | — | — | — |
| 6 | 3.65 | — | — | — | — | — | — |
| 5 | 3.35 | — | — | — | — | — | — |
| 4 | 2.85 | — | — | — | — | — | — |

Plotting these factors against external filtration for different K.V.P.'s results in the curves shown in Fig. 19. It is seen that although the F.O.R. falls progressively with decrease in K.V.P., the dependence on external filtration is more complex. From 3 mms. down to 0.3 mm. Al. filter thickness, the F.O.R. increases with a reduction in filtration, whereas below 0.3 mm. Al. there appears to be a temporary reversal in this relationship, the maximum values of F.O.R. lying at ~ 0.25 mm. Al. filtration. This effect is probably due to the complexity of the scatter distribution, but remains to be investigated theoretically. However, an analysis of EBBEHÖJ's (1948) depth dose curves revealed the same reversal effect, including the final increase in the F.O.R. as the filtration is reduced below 0.1 mm. Al. — thereby

[1] It will be noted that a high rate of fall in intensity corresponds to a low F.O.R., but the alternative use of the reciprocal of the F.O.R. was discarded as it leads to fractional values. See note in § 13 (a) for clinicians.

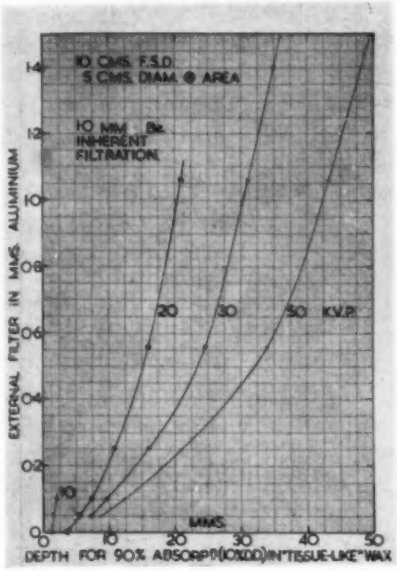


Fig. 18. The dependence of the »90 % absorbed« depth in »tissue« on K.V.P. and filtration.

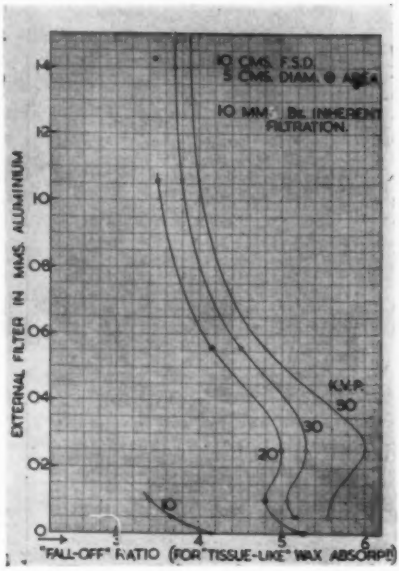


Fig. 19. The dependence of the »fall-off« ratio on K.V.P. and filtration.

providing confirmation for the above experimental results, though Ebbehöj's data covers a much more limited range.

(c) *The relation of the F.O.R. to H.V.D.'s*

The practical value of the fall-off ratio lies in its relationship to the H.V.D. This can be seen by plotting the H.V.D. against K.V.P. for a series of values of the F.O.R., as shown in Fig. 20. Thus, for one particular H.V.D., it is seen that the F.O.R. varies over a wide range. For example, for an H.V.D. of 1.2 mms. the F.O.R. falls from 6.0 to 3.6 as the K.V.P. is reduced from 50 to 12.

A range of filtration relating the H.V.D.'s to the K.V.P.'s is also included in this chart in order to indicate how any particular H.V.D. can be obtained at different K.V.P.'s by choosing the appropriate filtration. However, from a practical standpoint, it is advisable to limit the number of separate filters in use to about six. These should be chosen such as to enable one to obtain all H.V.D.'s (See Fig. 20), and any overlapping in this respect will lead to a wider selection of F.O.R.'s and S.D.R.'s (See Fig. 15, § 10 (b)). Further, even when one restricts oneself

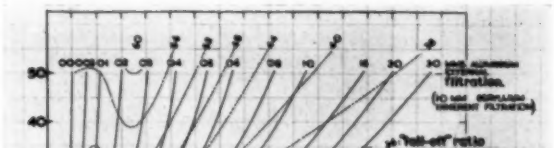


Fig. 20. The dependence of half-value-depth in »tissue« (H.V.D.) on K.V.P. and filtration, and of the »fall-off« ratio on K.V.P. and H.V.D.

to a limited number of K.V.P. settings (in the interests of simplicity), the F.O.R. remains a useful variable though a small change in ones choice of H.V.D. may then be necessary. It will be seen, for example, in Table IX § 13 (b) that for a 90 % absorption depth of 21 mms. the H.V.D. may fall at either 3.5 or 6.0 mms., and conversely, for an H.V.D. of 1.55 mms. the 90 % absorption depth may lie at 7.4 or 8.6 mms.

(d) *Dependence of the F.O.R. on Area, F.S.D. and Tube current*

From the measurements made in deriving the relationship between the H.V.D. and the area, F.S.D. and tube current, the corresponding data relating to the F.O.R. can be derived from the complete depth dose curves involved. In this way it is found that the F.O.R. is approximately independent of the tube current, and as it depends on the ratio of two readings, each of which are dependent in a similar manner on the area and F.S.D. concerned, the assumption of its independence from these two variables entails a second order error only.

(e) *The relation of the F.O.R. to the S.D.R.*

Comparison of Figs. 15 (§ 10 (b)) and 20 (§ 11 (c)) yield some very interesting results.

For a particular H.V.D. the S.D.R. is seen to rise rapidly with K.V.P. (Fig. 15) for apart from the increased output due to the increase in K.V.P., the filtration has to be reduced at the same time in order to retain the chosen H.V.D. Thus, the use of a high K.V.P. for the radiation of chosen H.V.D. leads to a high dose rate, and hence correspondingly short treatment time, which is a great advantage in treating lesions in such sites as the buccal cavity. Moreover, since the dose rate can be reduced at the same K.V.P. and filtration conditions by simply reducing the tube current, it might be thought unnecessary to use lower K.V.P's

for any H.V.D. between 1.05 and 15.8 mms. However, a second consideration arises.

Turning to Fig. 20, it is seen that the F.O.R. at any particular H.V.D. rises with K.V.P., or in other words, the penetration of the radiation beyond the 50 % absorbed level tails off more slowly into the underlying tissue. This is generally undesirable, the ideal choice for a depth dose curve in superficial irradiations being that it should remain at 100% to the desired depth, and then fall sharply to zero. Since this aim is more closely realised for any chosen H.V.D. at low K.V.P.'s than high ones, this consideration is in opposition to that raised above in connection with the S.D.R. An example here is the treatment of superficial lesions situated just over some bones, when minimum irradiation of the latter is clearly desirable.

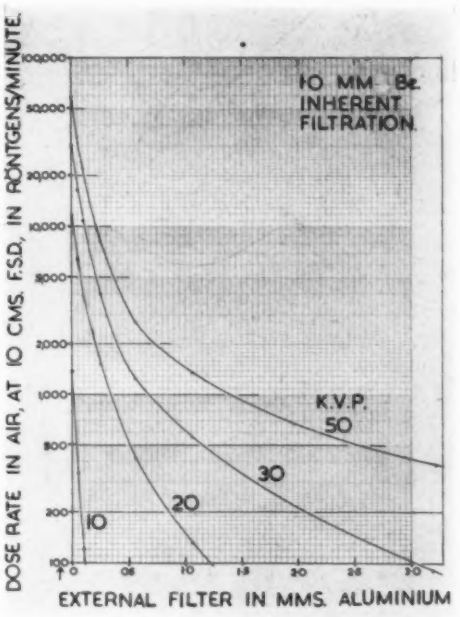


Fig. 21. Absorption curves in aluminium of the radiations, at four K.V.P. settings.

Accordingly, in the choice of treatment factors, a compromise may well be necessary between the S.D.R. and F.O.R. together with a possible small change in the specified H.V.D.

## 12. Aluminium Absorption Data

(a) *Derivation of half-value-layers (H.V.L.)*

Measured at 10 cms. F.S.D., air dose rates derived from the beryllium window tube run at 10, 20, 30 and 50 K.V.P. under a range of aluminium filtrations at each K.V.P., are plotted against the filtration on logarithmic paper in Fig. 21, from which it is seen that the higher voltage radiations remain relatively heterogeneous even under the maximum filtrations used.

By taking readings from these graphs, half-value-layers (H.V.L.) in aluminium for each filter thickness used at each K.V.P. setting can be derived. The values for 3.22 mms. Al. filter at 50 and 30 K.V.P., for

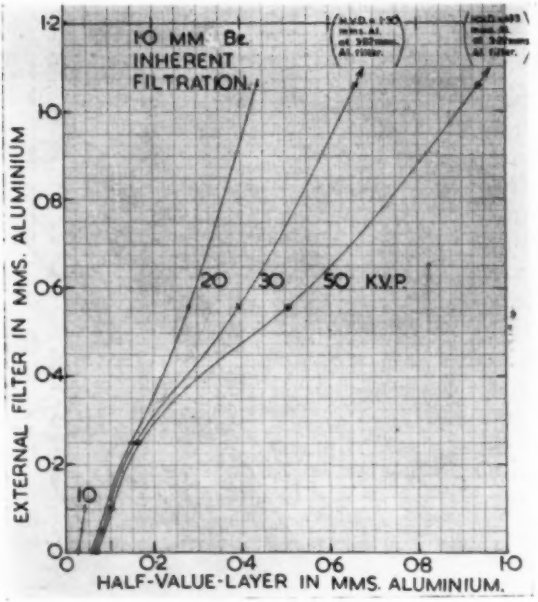


Fig. 22. The dependence of half-value-layer in aluminium on K.V.P. and filtration.

1.06 mms. at 20 K.V.P. and for 0.10 mm. at 10 K.V.P. were measured separately. The results are given in Table VII.

**Table VII**

| K.V.P. | External filtration in mms. aluminium | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.0 | 0.05 | 0.10 | 0.25 | 0.56 | 1.06 | 3.22 |
| | H.V.L. in mms. aluminium | | | | | | |
| 50 | 0.070 | 0.080 | 0.105 | 0.165 | 0.505 | 0.94 | 1.93 |
| 30 | 0.060 | 0.075 | 0.10 | 0.155 | 0.395 | 0.66 | 1.30 |
| 20 | 0.057 | 0.070 | 0.09 | 0.145 | 0.28 | 0.44 | — |
| 10 | 0.026 | 0.035 | 0.042 | — | — | — | — |

Plotting the H.V.L. in aluminium against the external filtration for each value of the K.V.P. provides H.V.L.'s for any filtration, as shown in Fig. 22. Comparing these graphs with those of Fig. 16 (§ 10 (b)), the same deviation from smoothness at an external filtration of $\sim 0.25$ mm. Al. is apparent.

Alternatively, the H.V.L. in Al. may be plotted against the K.V.P. for each filtration used, as shown in Fig. 23, these graphs being comparable with those of Fig. 15 relating to H.V.D.'s in »tissue».

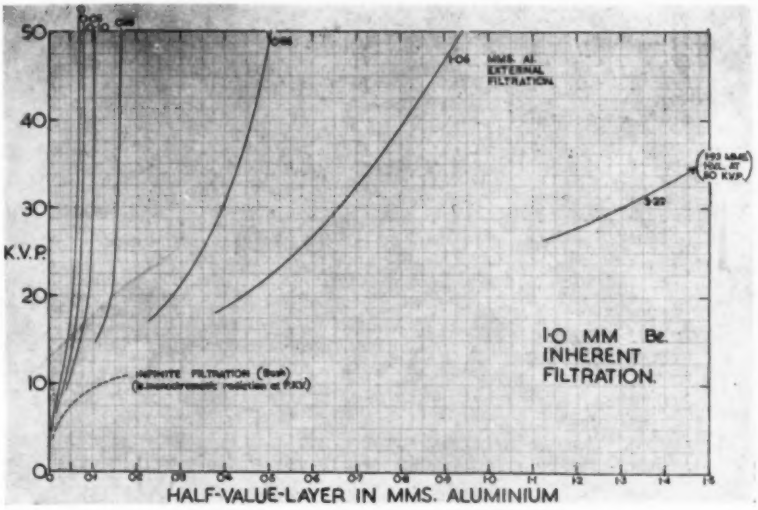


Fig. 23. The dependence of half-value-layer in aluminium on K.V.P. and filtration.

Following upon BUSH's calculations (see § 9 (h)), an additional curve has been included in Fig. 23; based upon the absorption data for a homogeneous beam at the peak K.V., the curve provides data corresponding to infinite filtration, thereby confirming the double bend found experimentally in the K.V.P.—H.V.L. curves for low filtrations as the K.V.P. is reduced.

(b) *The relation of H.V.L. in aluminium to H.V.D. in »tissue»*

As previously explained, the H.V.L. in Al. forms a measure of the radiation quality, closely related to the emitted spectral distribution as transmitted by the beryllium window; on the other hand, the H.V.D. in »tissue» is a measure of the penetration and includes the scatter contributions, thereby depending also on the field area and F.S.D. concerned. However, standardising these factors at 5.0 cms. diameter circle and 10 cms. F.S.D., the corresponding values of H.V.L. in Al. and H.V.D. in »tissue» have been plotted in Fig. 24 over the full range of qualities used. It is seen that except at Grenz ray qualities, there is an appreciable K.V.P. dependence. Thus, for a particular quality expressed in terms of Al. H.V.L., the penetration due to scatter contributions will increase appreciably with the K.V.P. used, as will the 90 % depth even in relation to the increased H.V.D., — as shown by the F.O.R. data indicated on the graphs.

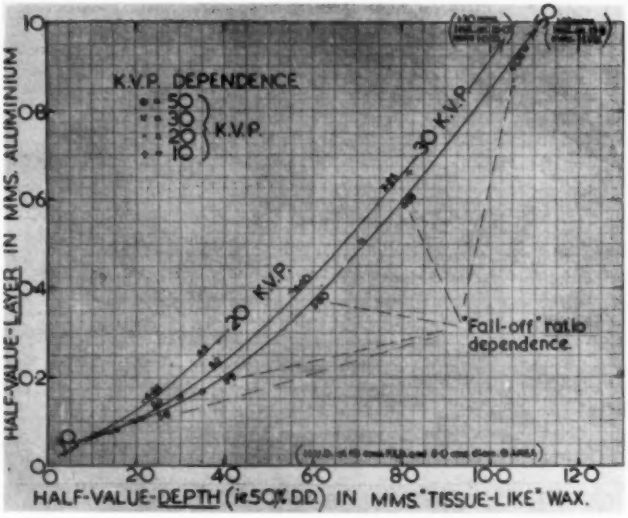


Fig. 24. The relation of half-value-depth in »tissue« to half-value-layer in aluminium at different K.V.P.'s.

(c) *Comparison with other available data relating to H.V.L.'s in aluminium.*

At low filtrations, comparison is possible with the results of BUSH's calculated data (see § 9 (h)). As in the case of the H.V.D. data (§ 10 (f)), it is found that the assumption of an additional 0.2 mm. Be. window thickness (*i. e.* approx. 0.025 mm. Al.) leads to a good agreement.

**Table VIII**

| K.V.P. | mms. Al. ext. filtration | mms. Al. H.V.L. theoretical data (Bush) | mms. Al. ext. filtration | mms. Al. H.V.L. experimental data (Table VII) |
|---|---|---|---|---|
| 50 | 0.0 | 0.039 | 0.0 | 0.070 |
| | 0.025 | 0.065 | | |
| 30 | 0.0 | 0.033 | 0.0 | 0.060 |
| | 0.025 | 0.057 | | |
| 20 | 0.0 | 0.027 | 0.0 | 0.057 |
| | 0.025 | 0.047 | | |
| 10 | 0.0 | 0.0175 | 0.0 | 0.026 |
| | 0.025 | 0.025 | | |

The only published data relating to Al. H.V.L.'s for radiations from beryllium window tubes is that of BRAESTRUP (1945) and BIRKMAN

(1948). The former was measured at a constant potential limited to 50 K.V. only, but covers a wide range of filtrations.

Although his results are in approximate agreement with those given in Table VII for the lower filtrations (0.0—0.10 mm. Al.), his H.V.L. data for harder radiations are a little greater. This could be accounted for by the inferred greater beryllium thickness, used in the present work, off-setting the reduction due to the employment of a fluctuating potential, an effect which would operate only at low filtrations.

BIRKMAN (1948), on the other hand, used fluctuating potentials, though at 50 K.V.P. only, but his tentative results are 30 % higher at 0.5 mm. Al. and 30 % lower at 3 mms. Al. filtration than those of Table VII (§ 12 (a)).

### 13. A Chart and Table for Treatment Planning

(a) *Suggested factors to be specified by the clinician*

The following specifications are put forward on the basis of the physical results obtained in the present investigation; whether the slight increase in complexity over the normal techniques now generally employed will prove to be justified can only be known from the clinical results obtained. However, to make the best use of the full potentialities of the apparatus, the following data is required upon which the optimum settings can be derived for any given treatment.

(i) *Penetration:* expressed in terms of the

(1) H.V.D. — generally the estimated total thickness of the lesion to be treated;

Or (2) 90 % absorption depth — in cases where this is the essential criterion (from the standpoint of avoiding damage to underlying bones or tissues);

Or, occasionally (3) a chosen percentage depth dose at a given depth.

(ii) The relative importance of a high *dose rate* or a rapid[1] »*fall-off*».

(iii) The choice of *applicator*, thus determining the F.S.D.; together with the *area* to be irradiated (if not the whole applicator field) for penetrations greater than 3.5 mms. H.V.D. (See § 14).

(iv) *Total dose* to skin surface or at H.V.D. level, whether fractionated, together with the approximate *treatment time* desired.

In practice, it has been found sufficient to prescribe for the vast majority of treatments in terms of the first alternative in Section (i) so Table IX has been designed with the H.V.D. as the basic factor.

[1] The use of the word »rapid» is recommended here to avoid any risk of confusion. A rapid »fall-off» corresponds to a low F.O.R. (See § 11 (b)).

**Table IX, Part I**

*Data directly applicable to a 5.0 cms Diameter Field Area at 10 cms F.S.D.*

| Ref. No. | 90 % abs[d] depth in mms wax | F.O.R. (90 % abs[l] / D. / H.V.D.) | H.V.D. in mms »tissue« | K.V.P. | External Filter mms Al. | 50.0 mA | | Similar pairs of columns (Volt[r] sett[g] — r/min) for tube currents of 25.0, 10.0 and 5.0 mA | 2.5 mA | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Volt[r] sett[g] | r/min | | Volt[r] sett[g] | r/min |
| 1 | 58.5 | 3.7 | 15.8 | 50 | 3.22 | 185 | 455 | | 195 | 18.7 |
| 2 | 42.5 | 3.55 | 12.0 | 30 | 3.22 | 121 | 100 | | 119 | 4.25 |
| 3 | 43.2 | 4.00 | 10.8 | 50 | 1.06 | 185 | 1,500 | | 195 | 69.0 |
| 4 | 31.2 | 3.80 | 8.20 | 30 | 1.06 | 121 | 600 | | 119 | 33.0 |
| 5 | 34.1 | 4.80 | 7.10 | 50 | 0.56 | 185 | 2,860 | | 195 | 154 |
| 6 | 21.0 | 3.50 | 6.00 | 20 | 1.06 | 85.0 | 137 | | 74.0 | 7.37 |
| 7 | 24.7 | 4.50 | 5.50 | 30 | 0.56 | 121 | 1,290 | | 119 | 71.0 |
| 8 | 16.0 | 4.15 | 3.85 | 20 | 0.56 | 85.0 | 422 | | 74.0 | 22.4 |
| 9 | 21.0 | 6.00 | 3.50 | 50 | 0.25 | 185 | 8,250 | | 195 | 400 |
| 10 | 15.9 | 5.30 | 3.00 | 30 | 0.25 | 121 | 3,960 | | 119 | 218 |
| 11 | 10.7 | 5.00 | 2.15 | 20 | 0.25 | 85.0 | 1,530 | | 74.0 | 91.0 |
| 12 | 11.7 | 5.60 | 2.10 | 50 | 0.10 | 185 | 22,000 | | 195 | 1,020 |
| 13 | 9.60 | 5.05 | 1.90 | 30 | 0.10 | 121 | 10,900 | | 119 | 530 |
| 14 | 7.40 | 4.80 | 1.55 | 20 | 0.10 | 85.0 | 3,900 | | 74.0 | 233 |
| 15 | 8.60 | 5.55 | 1.55 | 50 | 0.05 | 185 | 34,000 | | 195 | 1,460 |
| 16 | 7.20 | 5.15 | 1.40 | 30 | 0.05 | 121 | 16,500 | | 119 | 955 |
| 17 | 5.10 | 4.90 | 1.10 | 20 | 0.05 | 85.0 | 6,400 | | 74.0 | 400 |
| 18 | — | — | 1.05 | 50 | 0 | 185 | 59,000 | | 195 | — |
| 19 | — | — | 0.90 | 30 | 0 | 121 | 30,300 | | 119 | — |
| 20 | 3.68 | 5.25 | 0.70 | 20 | 0 | 85.0 | 11,600 | | 74.0 | 778 |
| 21 | 2.14 | 3.40 | 0.63 | 10 | 0.10 | 46.5 | 120 | | 35.0 | 8.90 |
| 22 | 1.89 | 3.65 | 0.52 | 10 | 0.05 | 46.5 | 340 | | 35.0 | 25.2 |
| 23 | 1.50 | 4.15 | 0.36 | 10 | 0 | 46.5 | 1,380 | | 35.0 | 121 |
| 24 | 1.15 | 3.95 | 0.29 | 8 | 0 | 43.0 | 770 | | 30.4 | 81.2 |
| 25 | 0.81 | 3.65 | 0.22 | 6 | 0 | 39.0 | 353 | | 25.0 | 38.4 |
| 26 | 0.60 | 3.35 | 0.18 | 5 | 0 | 36.5 | 153 | | 22.0 | 14.1 |
| 27 | 0.40 | 2.85 | 0.14 | 4 | 0 | 33.5 | 25.8 | | — | — |

(b) *The derivation of a routine treatment-planning Table and Chart*

A choice of about six filter thicknesses, covering a wide range of H.V.D.'s can be selected from the K.V.P.—H.V.D. graphs given in Fig. 20 (§ 11 (c)). Next, in the interests of simplicity, a limited number of K.V.P. settings and tube currents may be adopted, the former being chosen to provide a well-spaced selection of H.V.D.'s for the chosen filtrations, and the latter providing a well-spaced choice of dose rates and hence treatment times for any given H.V.D.

Next, choosing the 5.0 cms. diameter circle field and 10 cms. F.S.D. as standard, Table IX has been constructed in the order of the H.V.D.

**Table IX, Part II**

*Multiplying Factors for Use with other Areas (1.5—10.0 cms Diameter ⊙'s) and at other F.S.D.'s (10—70 cms)*

| Ref. No. | Dependence of **S.D.R.** on F.S.D. & AREA: air loss & «inverse square» factor cms F.S.D. 20 | 30 | 50 | 70 | 1.5 cms diam. ⊙ | 10.0 cms diam. ⊙ | Dependence of **H.V.D.** on F.S.D. & AREA: cms. F.S.D. 20 | 30 | 50 | 70 | 1.5 cms diam. ⊙ | 10.0 cms diam. ⊙ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | $\left(\frac{1.00}{4}\right)$ | $\left(\frac{1.00}{9}\right)$ | $\left(\frac{1.00}{25}\right)$ | $\left(\frac{1.00}{49}\right)$ | 0.92 | 1.05 | 1.20 | 1.35 | 1.64 | 1.90 | 0.89 | 1.08 |
| 2 | | | | | 0.945 | 1.035 | 1.16 | 1.30 | 1.55 | 1.76 | 0.92 | 1.055 |
| 3 | | | 0.99/25 | 0.99/49 | 0.95 | 1.025 | 1.15 | 1.28 | 1.51 | 1.71 | 0.93 | 1.05 |
| 4 | | 0.99/9 | 0.98/25 | 0.97/49 | 0.97 | 1.02 | 1.12 | 1.23 | 1.40 | 1.55 | 0.95 | 1.03 |
| 5 | 0.99/4 | 0.98/9 | 0.97/25 | 0.96/49 | 0.975 | 1.01 | 1.11 | 1.20 | 1.35 | 1.49 | 0.955 | 1.025 |
| 6 | 0.98/4 | 0.97/9 | 0.95/25 | 0.94/49 | 0.98 | 1.005 | 1.09 | 1.17 | 1.31 | 1.43 | 0.965 | 1.02 |
| 7 | 0.98/4 | 0.96/9 | 0.94/25 | 0.92/49 | 0.985 | ▲ | 1.085 | 1.16 | 1.29 | 1.41 | 0.97 | 1.015 |
| 8 | 0.97/4 | 0.94/9 | 0.90/25 | 0.86/49 | 0.995 | | 1.075 | 1.14 | 1.26 | 1.37 | 0.98 | 1.005 |
| 9 | 0.96/4 | 0.93/9 | 0.89/25 | 0.85/49 | ▲ | | ▲ | 1.135 | 1.25 | 1.36 | 0.98 | ▲ |
| 10 | 0.96/4 | 0.92/9 | 0.87/25 | 0.82/49 | | | | ▲ | 1.245 | 1.355 | 0.985 | |
| 11 | 0.94/4 | 0.90/9 | 0.83/25 | 0.76/49 | | | | | ▲ | ▲ | 0.995 | |
| 12 | 0.94/4 | 0.90/9 | 0.83/25 | 0.76/49 | | | | | | | ▲ | |
| 13 | 0.94/4 | 0.89/9 | 0.82/25 | 0.74/49 | | | | | | | | |
| 14 | 0.93/4 | 0.88/9 | 0.79/25 | 0.70/49 | | | | | | | | |
| 15 | 0.93/4 | 0.88/9 | 0.79/25 | 0.70/49 | | | | | | | | |
| 16 | 0.93/4 | 0.87/9 | 0.77/25 | 0.68/49 | | | | | | | | |
| 17 | 0.92/4 | 0.85/9 | 0.73/25 | 0.62/49 | | | | | | | | |
| 18 | 0.91/4 | 0.84/9 | 0.72/25 | 0.61/49 | 1.00 | 1.00 | 1.07 | 1.13 | 1.24 | 1.35 | 1.00 | 1.00 |
| 19 | 0.90/4 | 0.82/9 | 0.68/25 | 0.56/49 | | | | | | | | |
| 20 | 0.88/4 | 0.78/9 | 0.61/25 | 0.48/49 | | | | | | | | |
| 21 | 0.87/4 | 0.76/9 | 0.58/25 | 0.45/49 | | | | | | | | |
| 22 | 0.84/4 | 0.71/9 | 0.53/25 | 0.39/49 | | | | | | | | |
| 23 | 0.78/4 | 0.64/9 | 0.44/25 | 0.28/49 | | | | | | | | |
| 24 | 0.75/4 | 0.60/9 | 0.38/25 | 0.20/49 | | | | | | | | |
| 25 | 0.73/4 | 0.57/9 | 0.33/25 | 0.12/49 | | | | | | | | |
| 26 | $<\left(\frac{0.7}{4}\right)$ | $<\left(\frac{0.5}{9}\right)$ | $<\left(\frac{0.3}{25}\right)$ | $<\left(\frac{0.1}{49}\right)$ | ▼ | ▼ | ▼ | ▼ | ▼ | ▼ | ▼ | ▼ |
| 27 | | | | | | | | | | | | |

obtainable with the K.V.P. settings and filtrations adopted, whatever order these latter two factors may take in the Table. Thence, by combining some of the data previously given in Tables I, IV, V and VI, together with that contained in Figs. 6, 10, 12 and 17, the final working Table covering a range of areas and F.S.D.'s has been produced. This Table[1] (IX) covers all cases except those specified in terms of the alter-

[1] It must be emphasized that the dose rate data (and pre-reading voltmeter settings) apply only to the Unit calibrated, but the results serve to illustrate the order of the outputs to be expected with other Units similarly energised (See PART I, § 3).

native § 13 (a) (i) (3) above, which necessitate the use of the depth dose curves also (Figs. 13—14, § 10 (a)).

Let us illustrate the use of this Table by discussing two examples.

(I) Treatment of a 5 cms. diam. field at 10 cms. F.S.D.: If the H.V.D. has been specified, say 3.7 mms. tissue, then the two nearest available values in the fourth column of the Table are seen to be 3.85 and 3.5 mms. The former relates to conditions in which the F.O.R. is 4.15 and maximum S.D.R. is 422 r/min., whereas in the latter case the F.O.R. is higher at 6.0 but the maximum S.D.R. is also higher at 8,250 r/min. The decision between the two neighbouring H.V.D.'s is then based on the relative importance of a rapid »fall-off« (low F.O.R.) and a high S.D.R. as specified by the clinician. Let us assume the 3.5 mm. H.V.D. is chosen, whence the K.V.P. (50) and external filtration (0.25 mm. Al.) follow directly. We are then presented not only with the 8,250 r/min. output figure, but with a range of five possible dose rates (actually 8,250, 4,150, 1,770, 825 and 400 r/min.) from which to choose. If the clinician desired to deliver a surface dose of 4,000 r in 1 min., then the second D.R. figure of 4,150 r/min. is appropriate, and the tube current (25 mA) and pre-reading voltmeter setting (177) follow directly.

(II) Treatment of a 10 cms. diam. field at 20 cms. F.S.D.: In this instance, the effects of the non-standard area and F.S.D. on both the H.V.D. and S.D.R. arise. Assuming that the same penetration (3.7 mms.) and surface dose (4,000 r) have been specified as in the previous example, we see from the Table that the influence on the 3.5 mms. H.V.D. of the increased area is negligible, whereas the increased F.S.D. leads to a 7.5 % increase in H.V.D. to 3.7 mms. (This increase must be borne in mind in choosing the H.V.D. in column four of the Table in the case of the harder radiation qualities.) Next, the influence on the S.D.R. of the increased area is negligible, but the increased F.S.D. leads not only to the four-fold »inverse-square« law reduction in D.R. but also to a 4 % air loss. Accordingly, the nearest approach to the desired 4,000 r/min. S.D.R. that can be achieved under the chosen K.V.P. filtration pair is $8{,}250 \times 0.96/4 = 2{,}000$ r/min., at a tube current of 50 mA and a pre-reading voltmeter setting of 185.

It will be noted that the effect of field area on the S.D.R. and H.V.D. need only be considered for penetrations in excess of 3.5 mms. whereas the effects of a change of F.S.D. must be considered at all qualities.

A specially constructed panel with a system of small lamps is under construction to facilitate the choice of these various factors.

An alternative approach, which though not designed for the determination of the actual treatment data, has proved very valuable for rapid reference of the significance of the several variables concerned. This consists in the construction of a combined chart, in several colours, of a

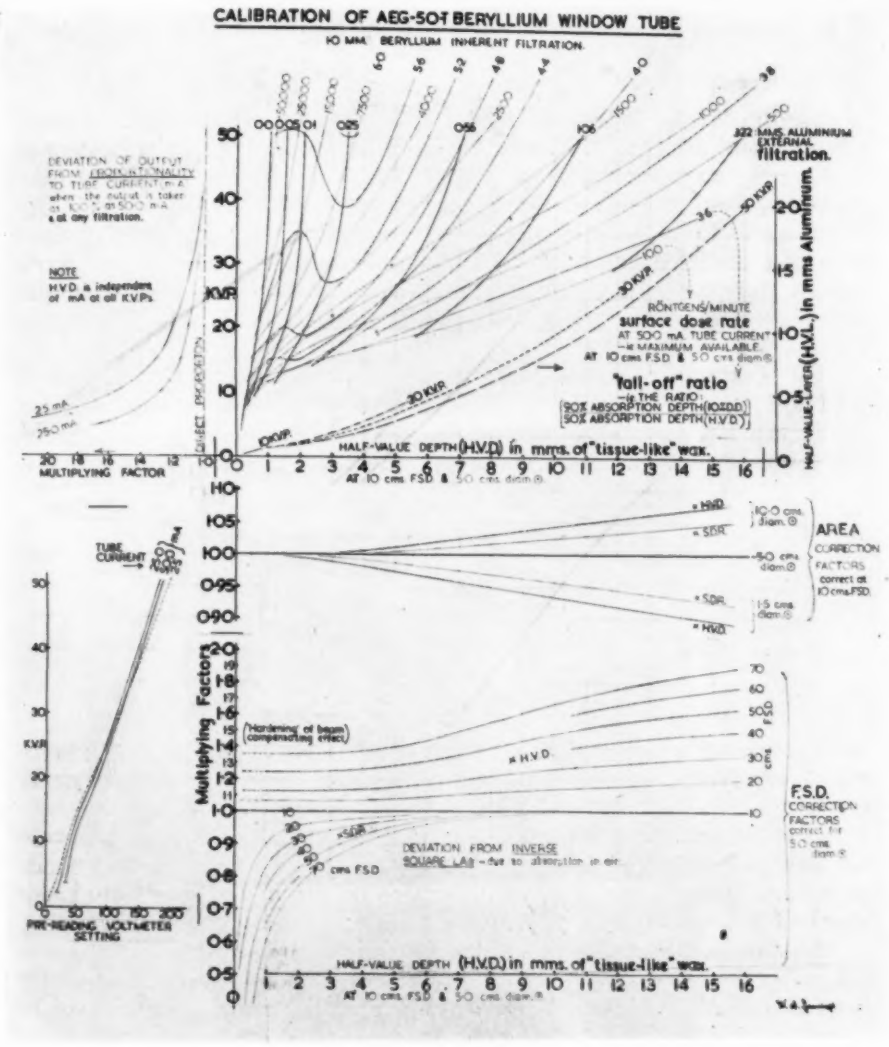
CALIBRATION OF AEG-50-T BERYLLIUM WINDOW TUBE
10 MM. BERYLLIUM INHERENT FILTRATION.
DEVIATION OF OUTPUT FROM LINEARITY TO TUBE CURRENT in mA when the output is taken as 100% at 500 mA at any filtration.
NOTE H.V.D. is independent of mA at all K.V.Ps.
RÖNTGENS/MINUTE surface dose rate AT 500 mA TUBE CURRENT —at MAXIMUM AVAILABLE AT 10 cms F.S.D. & 5.0 cms diam.
"fall-off" ratio = THE RATIO 50% ABSORPTION DEPTH (10 x 10) / 50% ABSORPTION DEPTH (H.V.D.)
HALF-VALUE DEPTH (H.V.D.) in mms. of "tissue-like" wax.
AT 10 cms F.S.D. & 5.0 cms diam.
HALF-VALUE LAYER (H.V.L.) in mms Aluminium
.22 MMS. ALUMINIUM EXTERNAL filtration.
MULTIPLYING FACTOR
TUBE CURRENT
PRE-READING VOLTMETER SETTING
AREA CORRECTION FACTORS correct at 10 cms. F.S.D.
F.S.D. CORRECTION FACTORS correct for 5.0 cms. diam.
Multiplying Factors
(Hardening of beam compensating effect)
DEVIATION FROM INVERSE SQUARE LAW — due to absorption in air.

Fig. 25. A sample comprehensive calibration chart derived for routine use with a particular Unit.

number of the graphs given in this work. Thus, including Figs. 6, 9, 10, 12, 15, 17, 20 (in part) and 24, the resulting chart (here in one colour only) is that shown in Fig. 25.

## 14. General Remarks Relating to Applicators and Lead »Cut-Outs«

(a) *Surface treatments*

The basic applicator used in the above work has a 5.0 cms. diameter circular field at 10 cms. F.S.D. This can be adapted to the treatment of any smaller area by the use of lead foil cut-outs. Lead foil, only a fraction of a mm. in thickness, can be cut with scissors without difficulty to the exact shape to be irradiated, the remaining foil being easily pressed into the precise form of the surrounding area; in this way several warts spaced over a small region can be treated at once by joint exposure provided they have the same thickness, the H.V.D. of the radiation being chosen accordingly.

By means of absorption measurements, the minimum thickness of lead foil required to cut out an adequate proportion of the radiation under the full range of qualities has been determined, and the results are given in Table X, to a first approximation.

**Table X**

| Percentage of $I_0$ absorbed by 0.1 mm. Al. foil | H.V.D. mms. tissue | H.V.L. mms. Al. | Thickness of lead foil which absorbs 99.5 % of $I_0$ |
|---|---|---|---|
| 91 % | 16 | 2.0 | 0.3 mm. |
| 95 % | 10 | 0.9 | 0.2 mm. |
| 99.5 % | 3 | 0.15 | 0.1 mm. |

The use of different foil thickness according to the penetration concerned is advocated, in view of the greater ease in cutting the finer thicknesses.

Lead rubber of 0.5 mm. lead equivalent is seen to be quite adequate for any protection requirement relating to the use of the Unit up to its maximum quality, and Fig. 26 illustrates its use in the successful treatment of a small rodent ulcer.

An alternative means of isolating certain irregular shaped cutaneous lesions by the use of a mixture of powdered lead and plasticine has recently been described by RASSIM (1949). Based upon his work, a mixture of 70 grams of powdered lead (100 mesh to dust) with 40 grams of plasticine and 2 ccs. of Arachis oil has been found to provide a most useful material. The non-irritating mixture obtained can be moulded to any shape and be used many times. A thickness of 1 mm. cuts out over 99 % of the hardest radiation available from the Unit (50 K.V.P., 3.22 mms. Al. filter). This technique is well suited to protection measures in such sites as the eye region, provided care is taken that the applicator does not

Fig. 26. The Use of Lead Rubber Cut-Outs in the treatment of a Rodent Ulcer.

(1) The treatment area is marked out
(2) A suitable cut-out is strapped on
(3) The Tube and applicator are brought into position for treatment.

cut or compress the mixture. A lead foil surround at the points of contact obviates such risks.

(b) *Intra-cavitary treatments*

Applicators with circular, oval or rectangular open ends of varying sizes (the field dimensions ranging from 1.5 to 4.0 cms.) have been found to be valuable, the F.S.D.'s lying between 10 and 18 cms. Some of these applicators are shown in Fig. 1, D (§ 5). This range allows of adequate lengths to reach the relevant sites, such as those in the buccal cavity (*e. g.* tonsils). However, the important factor in design relates to accuracy in placing the applicator port over the desired area. This may be done either by (i) the use of a retractable viewing telescope, though this results in an increase in F.S.D., or (ii) by means of easily detachable applicator end-sections. Thus, in the latter alternative, the applicator is placed in position first on its own, and the tube is then brought into position and attachment secured by some roentgen ray proof device.

(c) *Safety precautions*

It will be realised that the very high outputs which can be obtained from a beryllium window tube at 50 K.V.P. entail a markedly increased risk of accidents due to possible errors in setting. Accordingly, every precaution should be incorporated in the design of the Unit, particularly as regards errors in tube current setting by a factor of 10, for two scales are necessary for accuracy at 50 and 2.5 mA's; as regards the use of the correct filtration, and as regards timing accuracy. Thus, the filters are not inserted separately into each applicator as required, but are brought into position by the rotation of a permanently attached drum, electrical contacts lighting up an indicator panel, to minimise any risk of error. This filter drum can be seen on the tube shown in Fig. 26 (§ 14 (a)).

## 15. Biological Problems

The extended range of the roentgen dose rates and qualities available have led to important biological problems which have to be solved from the clinical standpoint before the new scope offered by the beryllium window Unit can be fully utilised in medical applications. For example, it is possible to deliver a surface dose of 1,000 r in one second; thus, if an accurate timing mechanism and adequate safety measures are incorporated, full doses can be delivered in treatment times of a few seconds, possibly hand-controlled, much as a photographer gives time exposures. But until the expected relations between the tissue reactions and total doses at such high dose rates are confirmed, such treatments

are unsafe. Further, the relation between the erythema dose[1] and H.V.D. is of great importance, and its possible dependence on a variation of the F.O.R. for a given H.V.D., not to mention the dependence on field area, site and patient requires careful investigation. All these problems, together with the determination of the conditions best suited to treatment with this Unit are being vigorously pursued by the medical staff of the Department on the basis of the physical data set forth in this work.

**Acknowledgements**

The author wishes to express his thanks to Dr. F. BUSH for permission to include some of his unpublished theoretical data, and for his interest and helpful discussions throughout the course of this work. Further, it is a pleasure to record the encouragement given by Mr. ANTHONY GREEN and Dr. R. F. HENDTLASS in relation to the above work, and for their advice concerning the clinical applications of the Unit. Credit is due to Mr. B. A. SPICER for constructing the very fine nylon mesh used in the modified Grenz ray chamber, and to Mr. E. V. MARSHALL for the preparation of the very thin »tissue-like» wax slabs used for depth dose measurements at all qualities. Finally, the author is indebted to Professor J. E. ROBERTS for kindly reading the draft manuscript of this paper, and for his valuable constructive criticisms.

**Appendix**

Following upon the completion of the above paper, the author has received a copy of a new paper by TROUT and GAGER[2] (July, 1949) relating to the physical characteristics of soft Roentgen rays, generated under pulsating tension between 30 and 100 K.V.P., from a beryllium window tube.

Although the range of their measurements scarcely overlaps that of the work here reported, comparisons are possible at two radiation qualities: namely 30 and 50 K.V.P., each without external filtration. Neither of these conditions has been recommended by the present author on account of the enormous dose rate at high tube currents, and high values of the F.O.R. at low tube currents. Moreover comparison is rendered uncertain by the use of different beryllium window thicknesses (2 mms. instead of the present 1 mm.), in view of the difficulty of allowing for the effects of this difference.

[1] The dose at the skin surface, whatever the dose delivered to the underlying tissue, which produces an erythema.

[2] TROUT, E. D., and GAGER, R. M., Am. J. Roent. 1949, 62, 91.

*Comparisons*

(i) The American measurements have all been made with a Victoreen nylon chamber (250 r), and the calibration factors given agree well with the data of Fig. 3 § 6.

(ii) The air absorption measurements are also in agreement with those given in Table IX § 13 (b).

(iii) Owing to the limitation imposed by their use of a 250 r condenser chamber, the output data given is limited to one graph. When this is redrawn on linear graph paper, it has the same form as those in Fig. 7 § 9 (a), but comparison is difficult as the tube current (s) used are not stated and the factor r/min/mA may not be independent of the mA setting.

(iv) Transmission data in aluminium compare satisfactorily, though the different inherent filtration is important here.

(v) The backscatter contribution are found to be negligible, in agreement with the present work.

(vi) Depth dose measurements are not in agreement. Two factors may account for the divergence. (a) The medium used by the American workers was lean beef in contrast to the present water-equivalent wax, and (b) a thimble type chamber has been used which would appear less satisfactory than the present mesh design with a plane surface, for depth dose measurements ranging between 0.3 mm and 1 cm. The chamber design difficulty is evidenced by the fact that the H.V.D. figures disagree by a factor of $\sim 3$, whereas the 90 % absorbed data differs by a factor of $\sim 1.5$, the present work yielding greater penetration figures in all cases. The influence of area and F.S.D. on the H.V.D.'s given are in agreement with the present results.

## SUMMARY

With a view to clinical application, all the relevant physical properties of low kilovoltage roentgen radiation are fully investigated by experiment. Using an AEG-50-T beryllium window Tube, radiation generated over the entire range from 2 to 50 K.V.P. at dose rates up to 60,000 r/min. have been measured under a wide range of filtrations, field areas, F.S.D.'s and tube currents.

PART I includes an introduction to the problem, a description of the generating equipment and measuring apparatus, together with a discussion relating to the calibration of the latter to cover all the radiation qualities and output rates concerned; also the medium used for depth dose measurements is considered.

PART II contains the experimental results. These relate to surface dose rates and their dependence on all the relevant variables, and to the depth dosage in »tissue» the »half-value-depth» forming a useful measure of »penetration». The ratio of the 90 % absorption depth to the H.V.D., or »fall-off» ratio, is then introduced and found to be a variable of practical significance when related to such factors as H.V.D. and S.D.R.

Data relating to the absorption of the radiation in aluminium are given and comparisons of the present results with other published work made whenever possible.

The information provided has been summarised into a convenient form for the routine clinical application of the optimum treatment settings.

## ZUSAMMENFASSUNG

Mit Rücksicht auf die klinischen Anwendungen werden alle zuständigen physikalischen Eigenschaften von bei niedrigen Spannungen erzeugten Röntgenstrahlen experimentell genau untersucht. An einer AEG-50-T-Röhre mit Berylliumfenster wurden Strahlungsmessungen ausgeführt bei Spannungen von 2 bis zu 50 kVs, Dosisleistungen bis zu 60,000 r/Min. und unter Variation der Filterung, der Feldgrösse, des Fokalabstandes und des Röhrenstromes über einem weiten Bereich.

Teil I giebt eine Einführung in das Problem, eine Beschreibung der Röntgenapparatur und der Messeinrichtung. Ferner wird die Eichung der letzteren für alle fraglichen Strahlungsqualitäten und Dosisleistungen sowie ein für Tiefendosismessungen geeignetes Phantommaterial besprochen.

Teil II giebt die experimentellen Resultate. Diese beziehen sich auf die Dosisleistung an der Oberfläche und ihre Abhängigkeit von allen zuständigen Variablen und auf die Tiefendosis in »Gewebe», wobei die »Halbwerttiefe» Variablen ein geeignetes Mass der »Durchdringungsfähigkeit» ergiebt. Das Verhältnis zwischen der »90 % Absorptionstiefe» zur Halbwertstiefe, oder das »Abfallverhältnis» wird dann eingeführt und zeigt sich von praktischer Bedeutung wenn es auf solche Faktoren wie die Halbwerttiefe und die Dosisleistung an der Oberfläche bezogen wird. Es werden Resultate über die Absorption der Strahlung in Aluminium gegeben und soweit möglich mit andererseits veröffentlichen Resultaten verglichten.

Die erhaltenen Resultate werden in einer für die Bestimmung der optimalen Behandlungseinstellungen in der klinischen Praxis geeigneten Form zusammengefasst.

## RÉSUMÉ

Toutes les propriétés physiques des Rayons Rœntgen de bas kilovoltage ont été etudiées expérimentalement et de façon complète en vue de leur utilisation clinique. En se servant d'un tube à fenêtre de Béryllium, marque AEG-50-T, l'auteur a mesuré les radiations sur une étendue de 2 à 50 Kilovolts, avec des doses jusqu'à 60,000 r. minute, en faisant varier dans de très grandes limites la filtration, la surface des champs, la distance focale et les courants du tube.

La I$^{e}$ Partie comprend une introduction au problème, une description du générateur et de l'appareil de mesure, ainsi qu'une discussion relative à l'étalonnage de ce dernier qui doit être adapté à toutes les qualités des radiations et au rendement qui sont en cause; de même a été traitée la question du milieu servant à mesurer les doses profondes.

La II$^{e}$ Partie apporte les résultats expérimentaux. Ceux-ci concernent les doses superficielles avec leur dépendance de tous les facteurs variables qui sont en jeu, et les doses profondes dans les »tissus» — la »demi-valeur en profondeur» donnant une mesure commode de la »pénétration». — Le rapport entre la profondeur d'absorption de 90 % des R. X. et la »demi-valeur en profondeur», dit aussi »rapport de diminution», est ensuite pris en considération et reconnu être un facteur variable d'importance pratique quand on le rapproche de facteurs tels que la »demi-valeur en profondeur» et la dose reçue en surface. Des données sur l'absorption des radiations par l'aluminium suivent,

et des comparaisons sont faites, chaque fois que c'est possible, entre les résultats de l'auteur et ceux rapportés dans d'autres publications.

Les renseignements fournis par l'auteur ont été résumés sous une forme commode, permettant de choisir le mantage optimum pour les traitements cliniques courants.

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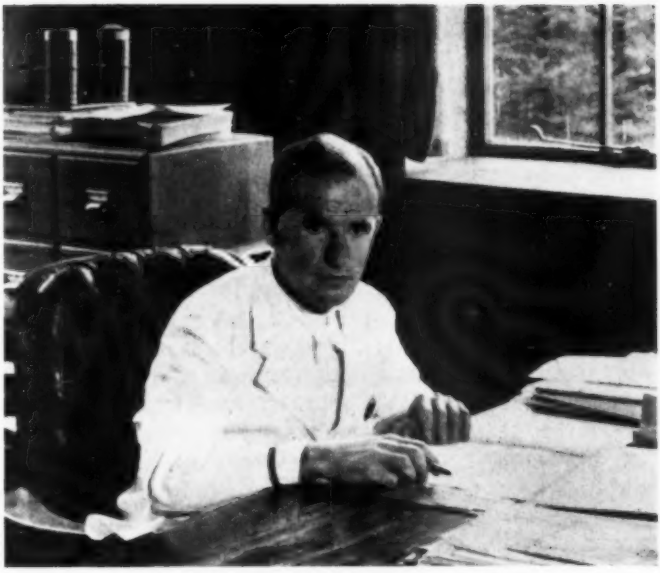

# ROLF BULL ENGELSTAD

## In Memoriam

10th August 1902—10th February 1950

Chief radiologist of The Norwegian Radium Hospital, ROLF BULL ENGELSTAD, M. D., died on February 10th 1950 at his home in Oslo, 47½ years old. This death means the termination of an unusually active and energetic life; even up to the last days before death overtook him he was standing in the centre of his activities.

Rolf Bull Engelstad had a wide clinical education before he started on his education as a specialist in medical radiology. After terms of study in Stockholm and Paris he was appointed junior assistant radiologist at The Norwegian Radium Hospital in 1932. During the years 1933 and 1934 he was chief of the Drammen Hospital Department of Roentgenology. In 1935 he was appointed senior assistant radiologist at The Norwegian Radium Hospital, and from 1938 he was head of the general department of this hospital. In 1935 he was created *doctor medicinae* of the University of Oslo on a radiobiological thesis with the title: »Über die Wirkungen der Röntgenstrahlen auf die Lungen».

Bull Engelstad had an intelligence which far exceeded the usual, and during the entire period when he was chief of The Norwegian Radium Hospital he was the leading personality in Norwegian radiation therapy and biology. His scientific production was considerable — it comprised many subjects within radiation therapy and biology. In recent years it has been cancer of the breast and its treatment which chiefly has interested him, and he published several papers on this subject. He has summed up the experience from his rich field of effort in his book: »Radiation Therapy. Textbook on Roentgen and Radium Irradiation». This manual has been of great value to older as well as younger radiologists in Norway, and also the practicians in other branches of medicine in our country have learnt to value this book and make use of it. He had a chance of demonstrating his ability as a teacher in his discourses to the medical students on the clinique of malignant tumours and their treatment. His clinical lectures with practical demonstrations were very valuable. In recent years much of his time and energy was occupied by the work involved in organizing the combat of cancer in Norway. He was one of the first to take the initiative of forming the *National Association against Cancer*, and from the inaugurating meeting of this association in 1948 he was its indefatigable president.

In *The Norwegian Medical Society* Bull Engelstad was in the front row of the active members. He contributed by numerous lectures and demonstrations to keep the members of the society orientated in the important branch of medicine which medical radiology represents, and acquainted them with the progress made in the field of radiation therapy and biology.

Bull Engelstad was also a capable linguist. Dating back to 1920, when he took his B. A. degree at the Lycée of Rouen, he preserved his love of Gallic culture. His thorough knowledge of the French language, and particularly of French medicine, has been invaluable to himself and his collaborators.

Colleagues at home and abroad will receive with sadness the information of his early death, and his memory will remain with them for long.

*Erik Poppe.*

# THE EXCHANGE OF DIAGRAMS AND DATA BETWEEN RADIATION THERAPY CENTRES[1]

A scheme organised by the Hospital Physicists' Association to facilitate the exchange of useful diagrams and data between radiotherapy centres has already been described (Read, 1945, 1946). Briefly, it was felt that most centres accumulate isodose and other charts, nomograms, machine drawings, and tabulated data which would often be useful to many other centres. Furthermore, diagrams in the literature are generally too small to be of practical use, and large copies of the originals might also be useful (proper precautions being taken to comply with copyright law). Therefore, catalogues have been issued by the Hospital Physicists' Association, describing all the material available of which copies can be supplied by the honorary secretary of the scheme, Catalogue A, issued in December 1944, contained 213 items, and catalogue B, of June 1946 over 200 more. By this time some 350 diagrams, etc. had been supplied, some of which went to the U. S. A., Canada, and New Zealand. By the end of 1949 the enquiries about the scheme and requests for catalogues, particularly from abroad, showed no signs of abatement, and about 400 copies of the first two catalogues had been distributed as follows:—

| | |
|---|---|
| British Isles | 52 per cent. |
| U.S.A. | 26 » |
| Canada | 7.5 » |
| Europe (excluding British Isles) | 6 » |
| Australasia | 3 » |
| India | 2.5 » |
| South Africa | 2 » |
| South America | 1 » |

The total number of diagrams, etc. now distributed exceeds 2,500, 45 per cent. of which have gone abroad. Within a single recent period of 12 months, nearly 900 items were despatched.

Enough new material has accumulated since the issue of catalogue B to justify the production of catalogue C (December 1949). This contains

[1] By kind permission of the Editors this article is reprinted from the February, 1950, issue of *The British Journal of Radiology*, page 139.

270 items classified by the number system used previously. Its scope is illustrated by the Table:—

1. X RAYS
   - 1.1. Isodose curves, and diagrams, etc., relating directly to X-ray therapy, *e. g.*, backscatter factors, depth doses:—
     - 1.1.1. Isodose curves of single fields ..... 157
     - 1.1.2. Isodose curves illustrating the summation of fields ..... 43
     - 1.1.3. Diagrams and data relating directly to X-ray therapy, *e. g.*, backscatter factors, depth doses ..... 5
   - 1.2. Wedge field and other non-standard isodose curves ..... 14
   - 1.4. Physical data relating solely to X radiation:—
     - 1.4.2. Data relating to half-value layers ..... 1
     - 1.4.3. Miscellaneous ..... 2

2. RADIUM AND RADON
   - 2.2. Isodose curves, and rules, graphs, etc., for dose calculation for radioactive sources:—
     - 2.2.1. Linear sources, $\gamma$ rays ..... 11
     - 2.2.5. Miscellaneous sources, $\gamma$ rays ..... 16
   - 2.4. Data relating to radon ..... 1

3. PHYSICAL DATA
   - 3.1. Scattering and absorption data for radiation in general:—
     - 3.1.1. Data relating to scattered radiation based on Klein-Nishina and Compton formulæ ..... 2
     - 3.1.3. Miscellaneous absorption and transmission data ..... 10
   - 3.2. Energy absorption, properties of the ionizing particles, distribution of ion pairs ..... 2

4. MATHEMATICAL DATA ..... 2

5. MACHINE DRAWINGS
   - 5.1. Ionization chambers ..... 3

7. REPRINTS OF WHICH STOCKS ARE EXHAUSTED ..... 1

The scheme has been run so that it is just self-supporting financially. The accumulation of negative copies of diagrams has made possible reductions in charges so that the average cost is now about 3*s.* 2*d.* (£ 0.16) per item, compared with 4*s.* 5*d.* (£ 0.22) in 1945. The majority of X-ray isodose charts may now be obtained on paper for about 2*s.* 0*d.* (£ 0.10) each.

Facilities have been granted to the Hospital Physicists' Association to demonstrate the working of the scheme at a stand in the Scientific Exhibition Section of the forthcoming 6th International Congress of Radiology in London next July. It is hoped that visitors, particularly

those from overseas, will profit from this opportunity to obtain first-hand information regarding the service provided.

It is desired to thank all those whose willing co-operation has made possible this effort to serve the interests of radiation therapy. The Association owes a special debt of gratitude to the British Empire Cancer Campaign, whose timely gift of £ 50 alleviated the initial financial difficulties.

Copies of catalogue C can be obtained (5*s*. or £ 0.25, post free) from the present Honorary Secretary of the Diagrams and Data Sub-Committee of the Hospital Physicists' Association, D. E. A. Jones, Mount Vernon Hospital, Northwood, Middlesex.

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